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SUMMARY

Tidewater and weather-exposure tests on various aluminum alloys, magnesium alloys, and stainless steels are now being conducted by the National Bureau of Standards. Exposures were begun in June 1938 and, according to present plans, are to continue over a 3-year period. The methods of exposure and the materials being investigated are described and the more important results obtained up to the conclusion of the first year's exposure are reported.

INTRODUCTION

Although the basic objective of the exposure program is to determine the relative susceptibility to corrosion, under saline conditions, of a number of alloys used in aircraft, several other features are being simultaneously investigated. These features include a study of the corrosion behavior of riveted and welded assemblies, of various dissimilar alloys in contact with each other, and of certain surface treatments and paint "schedules" used as protective coatings.

The tests embrace three distinct research projects dealing, respectively, with the behavior on exposure of (1) aluminum-rich alloys, (2) magnesium-rich alloys, and (3) stainless steels, all in the form of sheet, thin extrusions, or castings. The programs for the first two materials parallel each other rather closely, since the same features are being emphasized in the investigation of each. For this reason, in the present paper, the aluminum and the magnesium alloys are simultaneously considered as light metals, on the basis of the particular purpose for which the panels were designed. The stainless steels are separately discussed and the prime objective is to determine which of several compositions is the most corrosion resistant under the conditions of the test.

The authors wish to express their gratitude to the cooperating manufacturers who prepared the panels, namely, the Aluminum Company of America, the Dow Chemical Company, the American Steel and Wire Company, the Carnegie-Illinois Steel Corporation, the Edward G. Budd Company, the International Nickel Company, the Bell Aircraft Corporation, Fleetwings Incorporated, and the Naval Aircraft Factory; to the cooperating officials at the Hampton Roads and Coco Solo Naval Air Stations; and to the sponsors of the project, the Army Air Corps, the National Advisory Committee for Aeronautics, and the Bureau of Aeronautics of the Navy Department.

EXPOSURE TESTS ON LIGHT METALS

Procedure

Materials.- The chemical analyses of the aluminum and the magnesium alloys used in the investigation are given in table I, together with their conditions of fabrication, and the thickness. Details relative to heat treatment are contained in table II. The aluminum alloys of paramount interest are: (1) 24ST, a duralumin-type material; (2) Alclad 24ST, in which a coating on both surfaces, consisting of approximately 99.7 percent aluminum and constituting 10 percent of the total thickness of the sheet, protects the 24ST core; (3) 53ST, essentially a binary alloy containing 1.25 percent magnesium; and (4) 52S-1/2H, another binary alloy containing approximately 2.5 percent magnesium. The two magnesium alloys were: (1) Dowmetal M, essentially a binary alloy containing 1.4 percent manganese; and (2) Dowmetal H, a ternary alloy with approximately 6.5 percent aluminum and 3 percent zinc. These names have been used throughout the report for convenience, although the results are believed to be typical of the class represented and not of the specific alloy used.

Types of panel.- All the exposure panels were prepared by the cooperating manufacturers and have over-all dimensions of 4 by 14 inches (fig. 1). The thickness of sheet panels is usually 0.040 inch, but the thickness of extruded, cast, or forged sections varies up to a maximum of 0.25 inch (table I). Most of the panels were assembled in one of the three ways illustrated in figure 1: type 1 for the investigation of rivets or various paint schedules; type 2, for welds; and type 3, for dissimilar metals in contact. Seven panels of each kind were prepared, four for the tidewater tests and three for exposure to the atmosphere. All unpainted panels, prior to exposure, were cleaned free from grease in trichloroethylene vapor and were washed with alcohol.

Methods of exposure.- The tidewater and the weather-exposure tests were conducted at Boush Creek, at the Naval Air Station, Hampton Roads, Va. This site was selected because of temperate climate and marine conditions. Views of the exposure racks are shown in figure 2. The weather-exposure racks face northeast and are situated directly over the water, the bottom of the supports being approximately 2 feet above mean high tide. Panels are supported at an angle of 45°.

The tidewater panels are mounted edgewise, with the flat surfaces vertical (fig. 3) with bakelite separators, each 3 inches long, to hold the panels upright. Each separator was so designed that only four small projecting "points," each 0.008 square inch in area, actually come into contact with the panel; hence, they permit adequate drainage. Both the panels and the separators are suspended on bakelite-covered monel-metal rods, which, in turn, rest in slotted monel-metal angles. Monel-metal springs, next to the outermost separators on each end, assure continued close contact of the separators with the panels.

The tide range at the test site averages about 2-1/2 feet and the tidewater panels are situated (fig. 2) in the middle of this range. They are therefore completely immersed at high tide and out of water at low tide for approximately 5-hour periods twice every 24 hours.

Salinity determinations on a sample of water from Boush Creek revealed that the chloride (Cl) content was 12.2 parts per thousand, and the sulphate (SO_4) content 1.75 parts per thousand, while the pH was 8.0. Ocean water contains approximately 20 and 2.8 parts per thousand, respectively, of chloride and sulphate, and has a pH of 8.0 - 8.4. The sample tested from Boush Creek probably represents the minimum salinity at that locality, since it was removed at low tide and after several days of intermittent rainfall. It is believed that the Boush Creek water is comparable with ocean water as a corroding medium.

Inspections.- The test panels were placed in the exposure racks during the week of June 11, 1938. Some of the panels that were more susceptible to corrosion than others were withdrawn, from only the tidewater racks, after exposures of 2 days, 1 month, and 3 months. After an exposure of 7-1/2 months, a complete set of panels was removed from the tidewater racks, and some of the more susceptible panels were taken from the weather-exposure racks. At the end of the first year, another complete set was removed from the tidewater racks, and also a complete set from the weather-exposure racks (exclusive of those withdrawn after 7-1/2 months.

All panels in the tidewater tests gradually became covered with a mixture of organic green slime and colloidal mud, but only a very few barnacles were present at the end of the first year. The tidewater panels were cleaned, prior to examination, by rubbing them with a soft scrub brush and hot water. Care was taken to preserve all corrosion products in position as far as possible. The weather-exposure panels were not cleaned prior to examination but, in some instances, were lightly rubbed with a soft cloth to remove adhering dust.

The progress of corrosive attack has been closely followed by means of macroscopic examinations and natural-size photographs of each panel. The results are presented in this report by reproductions of the photographs. Several of the panels will ultimately be dismantled to permit more thorough examinations of faying surfaces and to make such physical tests and microscopic examinations as are considered necessary.

The system for identification of the photographs in this report is as follows. The larger letters at the tops or the bottoms of vertical columns apply to each column in its entirety. Similar letters on the right of horizontal rows likewise apply to the entire row. Smaller lettering is applicable either to all the photographs of a figure or to detailed units of each panel, the arrangement being evident.

Investigation of Rivets

Riveted aluminum-alloy panels.- A determination was made of the electrolytic effects involved when rivets of 53ST and anodized 17ST and A-17ST (table I, items 13 - 15) are used for joining 52S-1/2H, 53ST, Alclad 24ST, and anodized 24ST alloys (table I, items 2 - 5).

Type 1 panels (fig. 1) were used throughout, and the faying surfaces were insulated with Neoprene PAW Tape, a fabric impregnated with synthetic chloroprene rubber and zinc chromate. All rivets were of the brazier-head type conforming to Navy Department Specification 43R5b, Type 2, Class A, with a 1/8-inch-diameter shank.

The 17ST and A17ST rivets were anodically treated in either one of two ways:

(1) Anodized in a 9-1/2-percent chromic acid electrolyte for 30 minutes at 40 volts and at 35° C.

(2) Anodized in a 15-percent sulphuric acid electrolyte at 25° C., with a current density of 12 amperes per square foot for 30 minutes. Sealed by impregnation with lead chromate formed by immersion in lead-acetate solution, washing, and then immersing in potassium dichromate solution. This treatment is commercially known as the Alumilite 205 process.

Half the total number of each kind of rivet was anodized by each of the methods, and the two types of coating were alternated when rivets were driven on the panels. All of the anodization of 24ST sheet was done in the chromic-acid electrolyte, with the exception of panels in which 53ST rivets appeared and upon which the sulphuric-acid electrolyte was used. The corrosion resistance of the sealed alumilite coatings was somewhat superior to that of the unsealed chromic-acid coatings, which checks the results of a previous investigation (reference 1).

Withdrawals of the riveted aluminum-alloy panels were made after 7-1/2 and 12 months in the tidewater tests and after an exposure of 12 months to the weather. The tidewater tests disclosed that both the anodized A-17ST and the 53ST rivets were anodic with respect to 24ST alloy. Corrosive attack was very severe, especially on the 53ST rivets, from which at the end of a year several heads had corroded completely off (fig. 4). On the other hand, corrosion of the anodized 17ST rivets used with 24ST alloy was only in its initial stage after 1 year's exposure. No attack whatever was observed after a year in tidewater on any of the rivets tested when they were used to join alloys 52S-1/2 H, 53ST, or Alclad 24ST (fig. 5). Hence, the differences in potentials involved for these combinations, in salt water, are either very small or the alloy of which the main panel consists is anodic with respect to these rivets. If the main panel is anodic with respect to the rivets, the surface area of the rivets was so small, as compared with that of the main panel, that no acceleration of attack on the panel material was noted.

The tidewater tests showed that alloy 52S-1/2 H was the most resistant to attack, with alloys 53ST (sheet or extruded) and Alclad 24ST only slightly less so. Alloy 24ST, anodized or untreated, was noticeably less resistant to attack. Unanodized forged 14ST panels (table I, item 1) corroded in a manner comparable with other duralumin-type alloys.

The initial withdrawals of the riveted aluminum-alloy panels in the weather-exposure racks occurred at the end of the first year (fig. 6). There was a marked difference in the behavior of these panels and those from the tidewater tests. No evidence appeared of accelerated attack on the rivet heads that could be attributed to differences in potential. The attack of the anodized A-17ST and the 53ST rivets used to join 24ST alloy was no worse than that of the anodized 17ST rivets. Both the main panels and the rivets possessed small localized areas of corrosive attack, particularly on their earthward surfaces. The anodically treated 24ST panels, however, were practically unattacked, indicating that no failure of the coating had yet occurred.

Riveted magnesium-alloy panels.- Dowmetal M (table I, item 17) was selected as the main-panel material in the investigation of the behavior of rivets on magnesium alloys. The rivets included 53ST and AM55S alloys (table I, items 15 and 16). Anodized 17ST rivets (table I, item 13) were used on several type 3 panels, and information was therefore obtained on their behavior. The type 1 panels were insulated with Neoprene PAW Tape at the faying surfaces; the type 3 panels were uninsulated. All the magnesium-alloy panels were anodically treated in accordance with Navy Specification PT13a, that is, anodized 1/2 hour at 2 amperes per square foot in an electrolyte containing 10-percent sodium dichromate and 2-percent sodium phosphate at a pH of 4.5. Prior to anodization, the panels were pickled for 5 minutes in a 15-percent solution of hydrofluoric acid. All magnesium-alloy parts in the exposure tests were given this protective surface treatment, unless otherwise stated. Since magnesium alloys would not be used on aircraft without the application of protective coatings, check sets of each panel were prepared in the painted condition.

The tidewater tests on unpainted panels conclusively showed that AM55S rivets were the most satisfactory for joining magnesium alloys (fig. 7). The 53ST and anodized 17ST rivets reacted with corrosion products formed from Dowmetal M, and corrosive attack began during the first day. At the end of 1 year, the heads had all corroded off the 53ST rivets, and the 17ST rivets had completely disintegrated; whereas, the AM55S rivets were still in good condition. Tests on unpainted panels were discontinued at the end of 1 year.

The condition of the painted panels exposed to tidewater is also shown in figure 7. The paint schedule on the type 1 panels (table III, schedule 8) differed slightly from that on the type 3 panels (table III, schedule 10), but both schedules consisted essentially of an aluminum-pigmented V10 varnish applied over a P27 primer. Paint failures began at the rivets after an exposure of about 1 month and, though considerably more advanced, were still practically confined to these areas at the end of 1 year. It is probable that, had the AM55S rivets been anodically treated, paint failures on their heads would have been minimized.

The results of the weather-exposure tests (fig. 8) confirmed those of the tidewater test, but corrosive attack on the rivet heads was very much less severe and the paint failures were much less advanced at the end of 7-1/2 months.

Investigation of Welds

Welded aluminum-alloy panels.- A study was made of the corrosion behavior of electric-resistance spot and seam welds and of gas welds on aluminum alloys. Welded panels were of type 2 (fig. 1), but the overlapping faying surfaces were absent on gas-welded panels, which were butt-welded. The alloys used for welded panels were Alclad 24ST, 52S-1/2 H, 53ST, and extruded 53ST (table I, items 3 - 6), all without protective coatings. In both the weather-exposure and the tidewater exposure tests the welds proved very corrosion resistant, and withdrawals were made only at the end of 1 year. Gas welds were of the following combinations:

Alloys Welded Together	Filler Rod
52S-1/2H sheet to itself	52S
52S-1/2H sheet to 53ST sheet	2S
52S-1/2H sheet to extruded 53ST plate	2S
Extruded 53ST plate to itself	53S

The freedom from corrosive attack on the tidewater panels (fig. 9) indicated the absence of pronounced electrolytic potential effects. Attack on the weather-exposure panels was confined to small, localized areas, principally on unwelded parts of the panel, and mostly on the earthward surfaces.

Spot-welded panels, on which dissimilar aluminum alloys were joined to each other, are also shown in figure 9. The corrosive attack on the welds was relatively very slight and no more than occurred on panels where alloys of the same composition were joined together (figs. 10 and 11). In general, however, the spot welds showed slightly more attack than the gas welds, the greatest amount being present on the 53ST panels and the least on the 52S-1/2H panels.

The seam welds tended to be somewhat less corrosion resistant than the corresponfing spot welds. The worst attack, although not severe after a year in tidewater, occurred on the 53ST sheet material (fig. 10). Both spot and seam welds were more corroded in the weather-exposure (fig. 11) than in the tidewater tests.

Welded magnesium-alloy panels.- The behavior of Dowmetal M alloy, anodized after welding, is illustrated in figure 12. It will be noted that, at the end of a year in the tidewater tests, the spot welds were severely attacked, both on painted and unpainted panels. Corrosion began within 2 days after installation on the unpainted spot welds and within a month on the painted spot welds. Corrosion at the unpainted gas welds was no worse than on the rest of the panel but, on the painted panel, failure occurred at the weld. The superiority of gas-welded over electric-resistance spot-welded Dowmetal M was also apparent from the weather-exposure test (fig. 12), but the attack was less severe.

Contacts with Dissimilar Metals

The frequent necessity, in aircraft construction, of contacts of dissimilar metals, makes the portion of the program devoted to the potential effects involved in such contacts of extreme importance. In order to obtain basic information, no insulating materials were used at the faying surfaces and the panels were not painted. Panels were of type 3 (fig. 1), with two 4- by 1-inch strips of the dissimilar alloy joined to the main panel at each end. Since the ratio of the areas of the dissimilar metals is often a determining factor in the resulting corrosion, many of the panels were prepared in such a way that the ratio was reversed with respect to each metal. If, for example, alloy A formed the main panel, and alloy B the strips, in one instance; in another, alloy B was the main panel and A the strips.

Contacts of aluminum alloys with each other.- The tidewater tests revealed that the potential differences were relatively low in various two-member combinations of alloys 52S-1/2H, 53ST, and Alclad 24ST (fig. 13). Each of these alloys, however, was anodic to 24ST and was attacked when in contact with it (fig. 14). Potential differences were highest for the 52S-1/2H and 53ST alloys, and these were very severely attacked when in the form of a 1-inch wide strip fastened to the main panel of the alloy 24ST. With the surface area relationships reversed, however, corrosion was much less severe.

Contacts of aluminum alloys with plated steel.- On a number of panels of aluminum alloys, a 1-inch strip of zinc- or cadmium-plated S.A.E. X4130 steel was used as the contacting dissimilar metal. The electrodeposited coating in each case was 0.0005 inch thick. Aluminum alloys 52S-1/2H, 53ST, and Alclad 24ST appeared anodic, or protective, to cadmium in both the tidewater and the weather-exposure tests (fig. 15). The aluminum alloys, however, were not severely attacked. Zinc, on the other hand, was anodic to the aluminum alloys, being more so to the 52S-1/2H and the 53ST alloys than to the Alclad 24ST and 24ST materials. The zinc coating was almost completely removed by corrosipn when in contact with the 52S-1/2H, 53ST, or Alclad 24ST panels; whereas, the cadmium coating, in contact with the same alloys, was practically unattacked. Both the coatings suffered severe corrosion when in contact with 24ST alloy.

Contacts of aluminum alloys with stainless steel.- Couplings of the aluminum alloys with stainless steel (table V, item 2) are shown in figure 16. The tidewater tests disclosed that stainless steel was definitely cathodic to the aluminum alloys, although a decided area effect was apparent. When the steel formed the main panel, the attack on the aluminum alloys was very much more severe than when the conditions were reversed. Potential differences appeared to be lower between the steel and the Alclad 24ST and 52S-1/2H alloys but, even in the weather-exposure tests, appreciable corrosive attack occurred.

A series of panels was included, at the request of the Bureau of Aeronautics, only in the tidewater tests, in which various methods of insulation at the faying surfaces were studied. Panels of type 1 (fig. 1) with stainless-steel strips (table V, item 9) were used on the following painted (table III, schedule 7) aluminum alloys; 52S-1/2H, anodized 17ST, anodized 24ST, Alclad 17ST; and on unpainted Alclad 17ST. Type AN430-D Thomson head, anodized 17ST rivets, were used throughout. The insulation systems at the faying surfaces were:

(1) No insulation.

(2) Four sheets 0.002-inch aluminum foil, Navy Specification AC11074, Grade A, with aluminum washers, Type AN960-A-6, under rivet heads.

(3) Cellulose Tape, Type 7278T, Minnesota Mining and Manufacturing Company.

(4) Grade A cotton Fabric, Navy Specification AC6-97, impregnated with Kauri (Bakelite Type) seam compound.

(5) Grade A Cotton Fabric, Navy Specification AC6-97, impregnated with commercial soya-bean oil and Dulux Clear Spar Varnish, Navy Specification V11c (1/2 plus 1/2).

(6) Grade A Cotton Fabric, Navy Specification AC6-97, impregnated with Bitumastic, Type B23.

After a year in the tidewater tests, the panels were removed, cleaned, inspected, and reinserted. No photographs were taken, but the following constituted the more important conclusions:

(1) The stainless-steel strips showed no attack on any of the panels.

(2) Rivet heads were practically unattacked on (a) all unpainted Alclad 17ST panels, irrespective of the system of insulation, and (b) all panels where the insulating medium was aluminum foil.

(3) Rivet heads were all fairly severely attacked on painted panels of Alclad 17ST, 17ST, and 24ST alloys, irrespective of the system of insulation. Rivet heads on 52S-1/2H panels were appreciably less attacked.

(4) Failures, extending 1/4 inch inward from the edges, were prevalent on all painted panels except 52S-1/2H, on which failure was in only the initial stages. On painted panels, less corrosion products were present on the 52S-1/2H and Alclad 17ST than on the remaining alloys.

(5) As judged by the quantity and the distribution of corrosion products present around the edges of the stainless-steel strips, the best systems of insulation were those in which impregnated cotton fabric was used. When impregnated with soya-bean oil plus varnish or with Kauri seam compound, the amount of corrosion products was relatively small and occurred at small local areas. When impregnated with bitumastic, the attack tended to be somewhat more general.

(6) The cellulose tape, aluminum foil, and noninsulated systems were relatively inefficient. Corrosion products were present in considerable quantity and were distributed more or less generally.

<u>Contacts of aluminum alloys with nickel alloys</u>.- The aluminum alloys were used as the 1-inch-wide contacting strip on a series of main panels consisting of nickel, monel metal, and Inconel. The tidewater and the weather-exposure tests revealed that the aluminum alloys were anodic toward these nickel alloys and were severely attacked when in contact with them (fig. 17). The potential differences involved were apparently of the same magnitude as those between the aluminum alloys and the stainless steel and indicate the advisability of insulating such contacts in practice.

<u>Contacts of aluminum alloys with magnesium alloys</u>.- The tidewater tests demonstrated that the magnesium alloys were anodic to the aluminum alloys and that the potential differences were very high. Extremely rapid attack occurred, accompanied by deposition of corrosion products on

the aluminum alloys; several unpainted panels were withdrawn after an exposure of 2 days. The Dowmetal M alloy was more rapidly attacked than the Dowmetal H alloy, the reverse of which was true when these materials were not in contact with dissimilar metals.

Microanalytical tests showed that basic magnesium carbonate was the principal product deposited on the aluminum alloys, together with approximately 3 percent of sodium chloride. The resulting coatings were exceedingly corrosive toward the aluminum alloys and, on unpainted panels, all the 1-inch-wide aluminum alloy strips were completely disintegrated by the end of the sixth month. The ultimate corrosion product on the aluminum-alloy strips consisted of hydrated aluminum oxides and small amounts of magnesium, sodium, and chloride ions. The disintegration of alloy 24ST, when it constituted the main panel and Dowmetal M the strips, was complete after 3 months, the metal being entirely converted into corrosion products.

Potential differences were highest between the magnesium alloys and the 24ST and the Alclad 24ST alloys and lowest with magnesium alloys and the 53ST and the 52S-1/2H alloys. The 53ST and the 52S-1/2H alloys are to be preferred when the use of aluminum in contact with magnesium alloys is necessary. Under severe corrosive conditions, however, the coupling of these materials is inadvisable. Tests on the unpainted panels were discontinued at the end of the first year, owing to the severity of the attack (fig. 18).

The insulation afforded by the paint coatings was insufficient to prevent fairly rapid attack in the tidewater tests. On the painted panels, paint failure on the aluminum alloy strips was practically complete at the third month, and the attack thereon was severe at the end of a year (fig. 19).

In the weather-exposure tests, on unpainted panels, the 1-inch-wide contacting strips of Dowmetal M on 24ST, Alclad 24ST, and 53ST alloys were completely disintegrated at the end of 6 months; similar strips were fairly severely attacked when joined to alloy 52S-1/2H. Under the same conditions, however, Dowmetal H strips were very much less attacked and were in no case disintegrated. When the Dowmetal alloys constituted the main panels and the aluminum alloys the strips, severe corrosion at the faying surfaces occurred only with the Alclad 24ST and 24ST combinations. On the painted panels, failures were relatively small after a year's exposure, being greatest on the Alclad 24ST and 24ST strips (fig. 19). Hence, with adequate insulation at the faying surfaces, provided that corrosive conditions are not too severe, these alloys could probably be used together successfully.

Contacts of magnesium alloys with each other.- The results of the action of Dowmetals M and H, when in contact with each other, are shown in figure 20. The tidewater tests revealed that Dowmetal M was anodic to Dowmetal H, and strips of the former disintegrated entirely, even on painted panels. In the weather-exposure tests, however, the attack was not severe, even on unpainted panels. Under relatively mild corrosive conditions, therefore, these couplings should give satisfactory service when given a protective paint coating.

Contacts of magnesium alloys with stainless steels.- The coupling of magnesium alloys with stainless steel (table V, item 2) proved the worst of all the dissimilar metal contacts tested, as the magnesium alloys were very severely attacked (fig. 20). Immediately after the first tidewater had covered the panels, violent bubbling of the water occurred, and the reaction was audible for a distance of approximately 15 feet. The Dowmetal M was attacked somewhat more rapidly than the Dowmetal H. An adherent white corrosion product was deposited on the steel; the deposit was 0.004 inch thick at the end of 2 days. The white deposit gradually became removed and the underlying steel was unattacked. When the main panels consisted of Dowmetals, they were attacked so severely around the edges of the stainless steel strips that most of the latter ultimately fell off. The appearance of panels at the end of a year in tidewater tests, and of 7-1/2 months in weather-exposure tests, is shown in figure 20. The attack was much less severe on the weather-exposure than on the tidewater panels, and failures on the painted panels were not very far advanced after 7-1/2 months.

Investigation of Protective Coatings

For the investigation of protective surface coatings, panels of type 1 (fig. 1) were used. The paint schedules (tables III and IV) were applied by the cooperating manufacturers who prepared the panels. The main body of each panel, and the strips attached thereto, were of the same alloy. Prior to assembly, the strips and the main panel were separately painted with all except the finish coat, which was applied after assembly. Rivets were given a "touch-up" with primer before the finish coat was applied.

Paints on anodized aluminum alloys.- A rather comprehensive research on the protection of aluminum alloys having already been completed (reference 1), only a few paint schedules, thought to be superior, were included in the present tests. All paints were applied to anodized 24ST alloy, and the strips were joined with anodized 17ST rivets. Panels were removed from the exposure racks only at the end of the first year (fig. 21). No failures on any of the paint schedules were in evidence on the weather-exposure panels. Likewise, in the tidewater tests, no failures were observed when two coats of V11 or V10 varnishes were applied over a P27 primer (table III, schedules 3 and 4), nor when three coats of V10 varnish (table III, schedule 5) constituted the schedule. Paint failures, entailing failure of the finish coats to adhere to the primer, were beginning with the L12a lacquer on a P27 primer (table III, schedule 1) and the 52V15 varnish on a P23 primer (table III, schedule 6). The 52V15 varnish on a P27 primer (table III, schedule 2) was in much better condition, but there were indications of failure in its earliest initial stages. To date, the tests have clearly indicated that properly protected duralumin alloys are very resistant to extremely corrosive conditions.

Surface treatments and paints on magnesium alloys.- The protective surface coatings on the magnesium alloys were applied with two aims in view, namely, to determine (1) the relative efficiencies of the various paint schedules and (2) the relative merits of the "chrome-pickle" and the anodic surface treatments. The panels consisted of either Dowmetal M or H throughout, with the exception of the rivets, which were unanodized AM55S alloy. The anodic treatment was performed in accordance with Navy Department Specification PT13a, as described earlier in this report. Extensive laboratory tests performed at the National Bureau of Standards have shown that improved corrosion resistance and better paint adherence generally result if the anodic treatment is applied for 1 hour, rather than for 30 minutes, as required in the specification. The chrome-pickle treatment entailed immersion of the panels for approximately 2 minutes at room temperature in a bath containing 1.5 pounds of sodium dichromate and 1.8 pints of concentrated nitric acid (specific gravity 1.42) per gallon of water.

The surface appearance of panels initially included in the program and exposed for 1 year to tidewater (fig. 22) indicated the possibility of using the alloys under relatively severely corrosive conditions, provided that the best available surface treatments and protective paint coatings are utilized.

Complete paint failure occurred on all the unanodized aluminum alloy AM55S rivet heads in approximately 3 months. The need for anodizing these rivets was apparent and some check panels on which this precaution was taken have recently been inserted in the racks. Initial paint failures also occurred during the third month's exposure only on the magnesium alloys with the inferior paint schedules.

For all practical purposes, the chrome-pickle and the anodic surface treatments were equally efficient with respect to paint adherence, although on Dowmetal H paint failures were generally somewhat more advanced on the anodized panels.

It will be noted (fig. 22) that, except for failure around the rivet heads, two of the paint schedules afforded relatively excellent protection after a year's exposure in tidewater (table III, schedules 10 and 12). This result attests to the considerable progress made in the development of methods for the protection of magnesium alloys; only a few years ago it would have been considered impossible to protect these materials for as long a time under such severely corrosive conditions. It is noteworthy also that, while five of the paint schedules included finish coats of aluminum-pigmented varnishes that conformed to Navy Specification V10, two of these proved much superior to the others. It follows that conformity to this specification is not necessarily an assurance of the highest merit attainable in a varnish.

In the weather-exposure tests (fig. 23), after a year, paint failures were confined to the AM55S rivet heads, except on two of the inferior schedules (table III, schedules 5 and 6), irrespective of the method of surface treatment.

A series of annealed Dowmetal M panels, prepared by the Bell Aircraft Company at the request of the Bureau of Aeronautics, was exposed to the weather, but not in the tidewater tests, at both Hampton Roads and Coco Solo. The paints, in each instance, were applied to chrome-pickled and anodized (PT13a) surfaces. In this series of panels, paints applied to anodized surfaces were in better condition at the end of the year than those on chrome-pickled surfaces. Two finish coats were applied over a P27 primer and all the paints were Berry Brothers' products (table III, schedules 14 - 23). The tests were discontinued at the end of a year, owing to the fact that paint failures were more or less general on all the panels (figs. 23 and 24).

The tests again emphasized the need for careful selection of paint schedules. For example, the use of unpigmented lacquers or varnishes applied to untreated surfaces (fig. 23) resulted in more or less uniform corrosion of the metal. Baking treatments afforded little, if any, improvement in protection. Although the corrosive attack was somewhat less when surface treatments were also utilized, the inferiority of the unpigmented paint coatings was evident. The orange-yellow and the Navy gray pigments in the L12 and L12a lacquers and in the E4D and E5D enamels (fig. 24) also proved unsatisfactory. These coatings were badly cracked and chalked at the end of the year. The aluminum-pigmented vehicles afforded the best protection, but failures were quite numerous on these.

EXPOSURE TESTS OF STAINLESS STEEL

Materials and Procedure

The principal purpose of the exposure tests of stainless steel was to establish the relative corrosion resistance of the 18-8 type alloys, with and without additions of the customary alloying elements, such as columbium, molybdenum, and titanium (table V). One alloy containing slightly higher quantities of chromium and nickel and another nominally containing 16 percent chromium and 1 percent nickel were also included. The stainless steels were in sheet form, 0.018 inch thick. All of the sheets, with the exception of the 16-1 chromium-nickel alloy, had polished finishes. All were passivated for approximately 1 hour in 20-percent nitric acid at about 60° C. Faying surfaces were protected with a petrolatum paste containing copper. The electric-resistance shot welding was done by the Edward G. Budd Company. Each weld was rubbed lightly with emery to remove layers on which carbide precipitation might have occurred.

For each alloy, seven shot-welded panels of type 2 (fig. 1) were exposed, along with seven unwelded 4- by 14-inch sheets. Four panels of each type were exposed to tidewater and three of each to the atmosphere. Complete sets were withdrawn from the racks after 7-1/2 months and, from the tidewater racks, after a year.

Supports for tidewater tests.- Most of the panels of stainless steel were supported in the tidewater racks in the same manner as the light metals (fig. 3), except that thin copper shims kept the bakelite separators from contact with the steel. A number of panels of straight 18-8 alloy were suspended in the tidewater racks between separators of materials such as wood, glass, hard rubber, bakelite, monel metal, copper, and brass. For each supporting material, panels were suspended by the "four-point" method used in the main program and also so that contact was established with the stainless steel over an area of approximately 1 square inch.

The tests have shown that any of the materials used are suitable for suspending stainless steel in tidewater tests, provided that the four-point method is used. Where the areas of contact were relatively large and no provision was made for drainage, "inert" materials such as wood, glass, hard rubber, and bakelite were relatively unsatisfactory (fig. 25), even though springs kept the suspending mediums in very close contact with the steel. Painting of wood and bakelite separators tended, if anything, to increase the severity of the attack. Monel metal, brass, or copper separators proved satisfactory irrespective of the method of suspension, or whether a complete electric circuit was possible. Owing to the possibility that they may influence the rate of attack on the panel, because of potential differences and the existence of electric circuits, it is deemed unwise to use dissimilar metals for supports in tidewater tests.

Results of Tests

Corrosion was much more noticeable on the stainless-steel panels exposed to the weather than on those in the tidewater tests. Panels exposed to the weather became covered more or less uniformly with thin, but adherent, rust films (fig. 26). The rust formed during the first month and gradually became slightly thicker during the year. Accumulation of dust and soot may have been partly responsible for the corrosion.

The quantity of rust present on the 16-1 chromium-nickel alloy was greater than on the others. The straight 18-8 and 19-9 types and the 18-8 type containing columbium or titanium all behaved approximately alike, and the rust film thereon was quite thick after a year. The amount of rust on the molybdenum-containing steel was very much less than on the others, and it was clearly the most corrosion resistant (fig. 26).

It may also be observed (fig. 26) that, in several instances, there was considerably more rust on the shot welds than on the rest of the panel. This rust, however, was not associated with deep pits. It is therefore probable that the physical properties of the sheet were not adversely affected, although it is planned to check this result by means of flexural fatigue tests on uncorroded and corroded panels. The welds on the molybdenum-bearing steel were much less rusted than on the others.

Corrosive attack on the tidewater panels (fig. 27) was slight and was confined to a few small localized areas. An exception was the 16-1 chromium-nickel alloy on which several areas of rust occurred. Two rusted areas, each roughly 1/2 inch in diameter, were present on panels of the straight 18-8 and 19-9 types, but these areas are scarcely sufficient evidence to warrant the conclusion that these materials are less corrosion resistant than the other alloys. A few of the shot welds showed some attack but no more than on the remainder of the panel.

In view of the superior corrosion resistance of the molybdenum-containing steel in the weather-exposure tests, additional panels were inserted at the end of the first year. These panels include two alloys, one with 2.7 percent, and the other with 3.6 percent molybdenum (table V, items 10 and 11). In addition to the determination of the relative merits of the higher and lower molybdenum contents, the tests will furnish information on the effectiveness of various surface treatments and of copper- and aluminum-bearing pastes at the faying surfaces. A series of stainless steels of various compositions is also being inserted in the tidewater racks at monthly intervals, in order to ascertain whether the season of initial exposure ultimately influences the rate of corrosion.

CONCLUSIONS

The conclusions that follow are principally based upon the behavior of the various materials when subjected to extreme saline conditions, as exemplified by the tidewater tests. The corrosion behavior of a metal is always a function of a specific combination of a number of variables. In the present investigation, for example, marked differences sometimes occurred in the corrosion of presumably identical panels, depending upon whether they were exposed in the tidewater or the weather-exposure tests. In fact, in a few instances the corrosive attack was more severe on panels exposed to the weather, which normally would be regarded as a less severe method of test. It is highly probable that, in general, under mild, nonsaline conditions of exposure, corrosion would have been very much less severe. Drastically different exposure conditions, such as are encountered in industrial centers, would also influence the corrosion behavior.

1. Alloy 52S-1/2H proved the most corrosion resistant of the aluminum alloys tested and also the one least attacked when in contact with other aluminum alloys, magnesium alloys, or stainless steels. Alloys 53ST, Alclad 24ST, and Alclad 17ST were likewise very resistant, but the two Alclads were somewhat more susceptible to attack when in contact with dissimilar alloys. Alloys containing copper, such as 17ST, 24ST, and 14ST, were much more susceptible to corrosion, especially when in contact with dissimilar metals.

2. Dowmetal M proved more resistant to corrosion than Dowmetal H, but the reverse was true when these magnesium alloys were in contact with dissimilar metals.

3. Stainless steel that comtained molybdenum proved more corrosion resistant than did those with additions of columbium or titanium, or than those without additional alloying elements. An alloy containing 16 percent chromium and 1 percent nickel was much more susceptible to corrosion than the others. The stainless steels corroded worse in the weather-exposure than in the tidewater tests.

4. In general, the magnesium alloys proved much more susceptible to attack than either the aluminum alloys or the stainless steels.

5. Anodized 17ST rivets proved far better than anodized A17ST or 53ST rivets for joining aluminum alloy 24ST, but all three were satisfactory for joining alloys 52S-1/2H, 53ST, or Alclad 24ST.

6. AM55S rivets proved far superior to 53ST or anodized 17ST rivets for joining magnesium alloys.

7. On aluminum alloys 52S-1/2H, 53ST, and Alclad 24ST, joined to themselves or to each other, gas welds proved very resistant to corrosion. Spot welds tended to be somewhat more susceptible to attack, while seam welds were considerably more susceptible. Welds on 53ST alloy were more prone to attack than welds on the other two.

8. On Dowmetal M spot welds were very susceptible to attack but gas welds were quite resistant. Gas welds, anodized but unpainted, were in quite good condition after a year in the tidewater tests.

9. Heavier formations of rust tended to form on the shot welds of stainless-steel panels exposed to the weather, than on the unwelded portions of the sheet. Welds showed the least rust on the molybdenum-containing steel.

10. Alloys 52S-1/2H, 53ST, and Alclad 24ST proved suitable for contact with each other, but all were anodic to alloy 24ST and were attacked when in contact with it. They were more severely attacked when their areas were small as compared with that of alloy 24ST, in which case alloy 52S-1/2H was very badly attacked.

11. Zinc coatings, electrodeposited on S.A.E. X4130 steel, proved unsatisfactory for contact with aluminum alloys, and were severely attacked. Cadmium-plated coatings proved satisfactory for contact with aluminum alloys 52S-1/2H and 53ST in the tidewater tests, and also with alloys Alclad 24ST and 24ST in the weather-exposure tests.

12. The aluminum alloys were all anodic to nickel and to nickel alloys such as monel metal and Inconel, and were severely attacked when in contact with them. The monel metal and the Inconel themselves proved very resistant in the tidewater tests, with nickel only slightly less so. The nickel alloys discolored to a mottled brown in the weather-exposure tests.

13. The aluminum alloys were all anodic to stainless steel, potential differences being of approximately the same magnitude as with the nickel alloys. Attack on the

aluminum alloys was much less severe when their areas were large as compared with the steel.

14. The magnesium alloys were very anodic to stainless steel and were very rapidly attacked when in contact with it.

15. Cotton fabrics impregnated with soya-bean oil and varnish or with a Kauri seam compound proved satisfactory for insulating the faying surfaces of panels consisting of stainless steel and painted aluminum alloys. Such insulation, however, occasionally resulted in more severe corrosion of rivet heads than occurred when no insulation was used. Cellulose tape, or aluminum foil, proved inadequate for insulation.

16. The magnesium alloys were very anodic to all the aluminum alloys and corroded with the formation of a product which, in turn, was very corrosive to the aluminum alloys. Alloys Alclad 24ST and 24ST were very badly affected.

17. Dowmetal M alloy was anodic to Dowmetal H alloy.

18. Good grades of varnishes conforming to Navy Department Specifications V10 or V11, and applied over P-27 primers, adequately protected anodized 24ST alloy in the tidewater tests.

19. The chrome-pickle and the anodic treatments (PT13a) on magnesium alloys were practically equally efficient in promoting paint adherence. Where dimensional changes are to be avoided, however, the anodic treatment is recommended.

20. The tests demonstrated that it is possible to protect magnesium alloys adequately against very severe corrosive conditions, but that the choice of surface treatment and paint schedules is restricted to a few combinations. Some aluminum-pigmented varnishes that conformed to Navy Department Specification V10 afforded adequate protection, while others that also conformed to the specification, failed. Clear lacquers and varnishes and those not pigmented with aluminum powder generally failed within a short time.

National Bureau of Standards,
September 28, 1939.

REFERENCE

1. Mutchler, Willard: The Effect of Continuous Weathering on Light Metal Alloys Used in Aircraft. T.R. No. 663, N.A.C.A., 1939.

TABLE I. Chemical Composition of Aluminum Alloys and Magnesium Alloys

Item	Designation of material[a]	Fabrication	Thickness (in.)	Chemical composition (percent)								Other elements
				Al[e]	Cu	Mg[e]	Mn	Cr	Fe	Si	Zn	
1	14ST	Forged plate	0.225	93.12	4.37	0.44	0.76	--	0.51	0.80	--	--
2	24ST	Sheet	.040	93.25	4.11	1.62	.66	--	.20	.16	--	--
3	Alclad 24ST[b]	do.	.040	93.25	4.11	1.62	.66	--	.20	.16	--	--
4	52S-1/2H	do.	.040	97.04	.01	2.41	.00	0.24	.21	.09	--	--
5	53ST	do.	.040	97.66	.02	1.25	.00	.24	.19	.64	--	--
6	53ST	Extruded plate	.125	97.60	.02	1.24	.01	.23	.16	.74	--	--
7	53ST[c]	do.	.125	97.58	.03	1.26	.00	.24	.18	.71	--	--
8	24ST[c]	do.	.125	93.11	4.23	1.54	.65	--	.22	.16	--	--
9	17ST[d]	Sheet	.064	94.37	3.73	.65	.55	.00	.30	.40	0.00	--
10	Alclad 17ST[d]	do.	.064	94.57	3.50	.68	.55	.00	.30	.40	.00	--
11	24ST[d]	do.	.064	94.05	3.75	1.50	.50	.00	.10	.10	.00	--
12	52S-1/2H[d]	do.	.064	96.89	.03	2.65	.01	.22	.10	.10	.00	--
13	17ST	Rivets	.125	94.09	3.94	.54	.54	.07	.56	.26	--	--
14	A17ST	do.	.125	96.36	2.46	.32	.02	.00	.44	.40	--	--
15	53ST	do.	.125	97.56	.01	1.21	.00	.27	.20	.75	--	--
16	AM55S	do.	.125	95.69	.01	4.09	.00	.00	.14	.07	--	--
17	Dowmetal M	Sheet	.060	.03	<.01	98.56	1.36	--	.011	<.01	--	Ca 0.27
18	Dowmetal H	Extruded plate	.182	6.3	.0005	90.25	.23	--	.008	<.01	3.2	Pb 0.01-.05
19	Dowmetal H[c]	Cast	.188	6.6	.001	89.90	.21	--	.007	.01	3.0	--

[a]Analyses by the cooperating manufacturers, unless otherwise indicated. The aluminum alloys were analyzed by the Aluminum Company of America; the magnesium alloys, by the Dow Chemical Company.

[b]The Alclad coating contained 0.06 percent Si, 0.17 percent Fe, 0.09 percent Cu, balance aluminum.

[c]Used for 1- by 4-inch strips.

[d]Analyses by the Naval Aircraft Factory. Elements, except copper and aluminum, were determined spectroscopically.

[e]Values exceeding 89 percent were obtained by difference.

TABLE II. Heat Treatments of the Aluminum Alloys

(All heat treatments were performed by the cooperating manufacturer, the Aluminum Company of America.)

Item[a]	Designation of material	Heating medium	Solution heat treatment temperature °F.	Quenchant	Aged
1	14ST	Air	930 - 950	Air	10 hours at 340°F.
2, 3	24ST and Alclad 24ST	Nitrate bath	910 - 930	Cold water	Room temperature
8	24ST	Air	910 - 930	do.	do.
5, 6	53ST	do.	960 - 980	do.	18 hours at 315°-325° F.
7	53ST	do.	960 - 980	do.	8 hours at 340° F.
15	53S	do.	960 - 980	do.	6 hours at 355° F.
13, 14[b]	17S and A17ST	do.	930 - 950	do.	Room temperature

[a]The numbers correspond with those in table I.

[b]All rivets were reheat-treated once, after anodizing and before driving, to permit forming of driven heads.

TABLE III. Paint Schedules Used for Protective Coatings on Aluminum and Magnesium Alloys

Paint schedule[a]	Coat	Designation in figures[b]	Paint schedule[a]	Coat	Designation in figures[b]
1	1 2, 3	Berry Bros. 316-A Fuller Lacquer L12a[c]	7[i]	1 2, 3	Sherwin-Williams 25996[e] Berry Bros. 9299[e]
2	1 2, 3	Berry Bros. 316-A Pratt & Lambert 10[e]	8[j]	1 2 3, 4	Watson-Dowmetal 1 Watson-Dowmetal 1[k] Brooklyn Varnish 74[e]
3	1 2, 3	Berry Bros. 316-A Dulux RC-147[e]	9[m]	1, 2 3, 4	Watson-Dowmetal 1 Brooklyn Varnish 74[e]
4	1 2, 3	Berry Bros. 316-A Dulux VC-779[e]	10[n]	1 2,3,4	Watson-Dowmetal 1 Brooklyn Varnish 74[e]
5	1,2,3	Dulux VC-779[e]	11	1 2	Bakelite XE-8483 Bakelite XE-8483[d]
6	1 2,3	Brooklyn Varnish P-14 Pratt & Lambert 10[e]		3, 4	Bakelite XE-6440[e]

[a]Paint schedules were used as follows: 1-4, on aluminum alloys only; 5-6, on both aluminum and magnesium alloys; 11-23, on magnesium alloys only, with schedules from 14 to 23 applied only to Dowmetal M panels prepared by the Bell Aircraft Factory.

[b]See table IV for the specifications to which the paints conform.

[c]Aluminum-pigmented, 1/2 pound per gallon, with No. 1571 Albron Extra Fine Lining Paste conforming to Navy Specification M211, Type B. This product was the one used on all aluminum-pigmented varnishes except those indicated by footnote f.

[d]Aluminum-pigmented, 1-1/2 ounces per gallon.

[e]Aluminum-pigmented, 1-1/4 pounds per gallon, when used on aluminum alloys, and 1-1/2 pounds per gallon, when used on magnesium alloys.

[f]Aluminum pigmented with 422-mesh Albron Extra Fine Powder conforming to Navy Specification 52Al, Type B.

[g]Orange-yellow pigmented with cadmium lithopone. Lacquer contains a maximum of 12-percent nitrocellulose, a minimum of 48-percent resin, and a minimum of 40-percent pigment.

[h]Clear lacquer applied only to polished surfaces. Coats air dried on some panels and oven dried on others.

TABLE III (Continued)

Paint schedule	Coat	Designation in figures[b]	Paint schedule	Coat	Designation in figures[b]
12	1	Bakelite XE-8483[d]	18	1	Berry Bros. P27
	2	Bakelite XE-8483[d]		2, 3	Berry Bros. L12a[g]
	3, 4	Bakelite XE-3944[e]			
13	1	Dulux F-63-X-48013	19	1	Berry Bros. P27
	2, 3	Dulux VC-779[e]		2, 3	Di Noc 2122[f, l]
14	1	Berry Bros. P27	20	1, 2	Di Noc 2122[h, l]
	2, 3	Berry Bros. L12[f]			
			21	1	Berry Bros. P27
15	1	Berry Bros. P27		2, 3	Berry Bros. E4D[o]
	2, 3	Berry Bros. L12[g]			
			22	1	Berry Bros. P27
16	1, 2	Berry Bros. L12[h]		2, 3	Berry Bros. E5D[p]
17	1	Berry Bros. P27	23	1	Berry Bros. P27
	2, 3	Berry Bros. L12a[f]		2, 3	Berry Bros. V10c[q]

[i]Schedule used on aluminum-alloy panels to which stainless-steel strips were joined for the study of insulation at faying surfaces.

[j]Schedule used only on magnesium-alloy panels prepared for the investigation of rivets.

[k]Aluminum-pigmented, 1 pound per gallon.

[l]Coats air dried on some panels and each baked 1 hour at 250° F. on others.

[m]Schedule used only on magnesium-alloy panels prepared for the investigation of welds.

[n]Schedule used also on panels on which magnesium alloys were in contact with dissimilar metals.

[o]A 33-gallon varnish, resin not specified, with a minimum of 48-percent pigment consisting entirely of lead chromate.

[p]Navy-gray pigmented with 48-percent titanium dioxide, 48-percent zinc, and 2-percent lampblack.

[q]Some panels pigmented as in footnote f, others not pigmented.

TABLE IV. The Paints and Varnishes Used, and the Specifications to Which the Products Conform

Trade name	Used in paint schedules[a]	Navy specification	Characteristics
Berry Bros. Berryloid Zinc Chromate Primer 316-A	1,2,3,4	P27b	Have a minimum nonvolatile of 60% containing about 45% vehicle and 55% pigment. Resin not specified. Pigments contain a minimum of 85% zinc chromate and a maximum of 15% magnesium silicate.
Berry Bros. Berryloid Zinc Chromate Primer	14,15,17-19, 21-23	P27	
Dupont Dulux Zinc Chromate Primer P-63-X-48013	13	P27b	
Sherwin-Williams Zinc Chromate Primer 25996	7	P27a	
Watson-Standard Co. Special Dowmetal Primer No. 1	8,9,10	P27[c]	
Bakelite Anti-Corrosive Primer XE-8483	11, 12	P27[c]	Has approximately 46% phenol formaldehyde resin, 39% zinc chromate, 7% mica.
Brooklyn Varnish Co. Kauri P-14 Primer	6	P23d	A 33-gallon, phenol formaldehyde varnish, with a minimum of 28% resin. Pigment contains 33% zinc chromate, 67% iron oxide.
Pratt & Lambert No. 10 Aluminum Mixing Varnish	2, 6	52V15b	A long oil, 66-gallon varnish, with resin a mixture of rosin ester and rosin, and a nonvolatile of about 52%

[a]Numbers correspond to those in table III.

[c]Products do not conform strictly to the Specification listed but are of a similar type.

TABLE IV (Continued)

Trade name	Used in paint schedules[a]	Navy specification	Characteristics
Dupont Dulux VC-779 Varnish Bakelite Marine Spar Varnish XE-6440 Berry Bros. Spar Varnish Brooklyn Varnish Co. No. 74, Spar Varnish	4,5,13 11 23 8,9,10	V10d V10 V10c V10d	33-gallon varnishes having a minimum nonvolatile of 60% which in turn contains a minimum of 28% phenol formaldehyde resin.
Bakelite Marine Spar Varnish XE-3944	12	V10[c]	A 12-1/2 gallon, phenol formaldehyde, varnish.
Dupont Dulux RC-147 Varnish Berry Bros. Glyceryl Phthalate Varnish 9299	3 7	V11 V11d	Have a minimum nonvolatile of 44%, containing in turn a minimum of 40% glyceryl phthalate resin.
Berry Bros. E4D Orange-Yellow Enamel	21	E4D	A 33-gallon varnish, resin not specified, with a minimum of 48% pigment consisting entirely of lead chromate.
Berry Bros. E5D Navy-Gray Enamel	22	E5D	Has a minimum of 25% glyceryl phthalate resin and 25% pigment, with a maximum of 50% volatile.
Berry Bros. L12 Lacquer	14,15,16	L12	A nitrocellulose lacquer.
Fuller Co. L12a Lacquer Berry Bros. L12a Lacquer	1 17, 18	L12a L12a	Contain a minimum nonvolatile of 30%, consisting of 20% maximum nitrocellulose, 80% minimum glyceryl phthalate resin.
Berry Bros. Di-Noc 2122 Lacquer	19, 20	--	Ingredients not furnished.

[a]Numbers correspond to those in table III.

[c]Products do not conform strictly to the Specification listed but are of a similar type.

TABLE V. Chemical Composition of the Cold-Rolled Stainless Steel Sheets

(Analyses made by the cooperating manufacturer, the American Steel and Wire Company. Ultimate tensile strengths of the materials ranged from 150,000 to 175,000 pounds per square inch.)

Item	Designation in figures 25-27	Commercial type	Chemical composition - percent							
			Cr	Ni	C	Mn	S	P	Si	Others
1	3.7 Mo	316	17.91	11.08	0.08	1.41	0.006	0.015	0.364	Mo 3.67
2	.5 Ti	321	17.56	9.12	.07	.41	.008	.015	.463	Ti .50
3	.5 Cb	347	17.84	9.90	.08	.46	.007	.015	.200	Cb .53
4[a]	.8 Cb	-	18.36	8.65	.08	.40	.020	.010	.42	Cb .80
5	18-8	302	17.8	7.30	.10	.59	-	-	.45	--
6	19-9	306	19.99	9.82	.09	.49	.010	.018	.271	--
7	contacts	304	18.54	8.17	.07	.54	.012	.007	.434	--
8	16-1	-	17.70	1.62	.08	.72	.021	.012	.518	--
9	--	b	18.3	8.4	.08	.33	-	-	-	--
10	--	316	17.79	10.72	.05	1.27	.012	.011	.34	Mo 2.70
11	--	317	18.80	13.70	.07	1.68	.014	.008	.29	Mo 3.60

[a]Heat-aged to 180,000 pounds per square inch.

[b]Material furnished by Sharon Steel Company and used for panels on which it was insulated from various aluminum alloys.

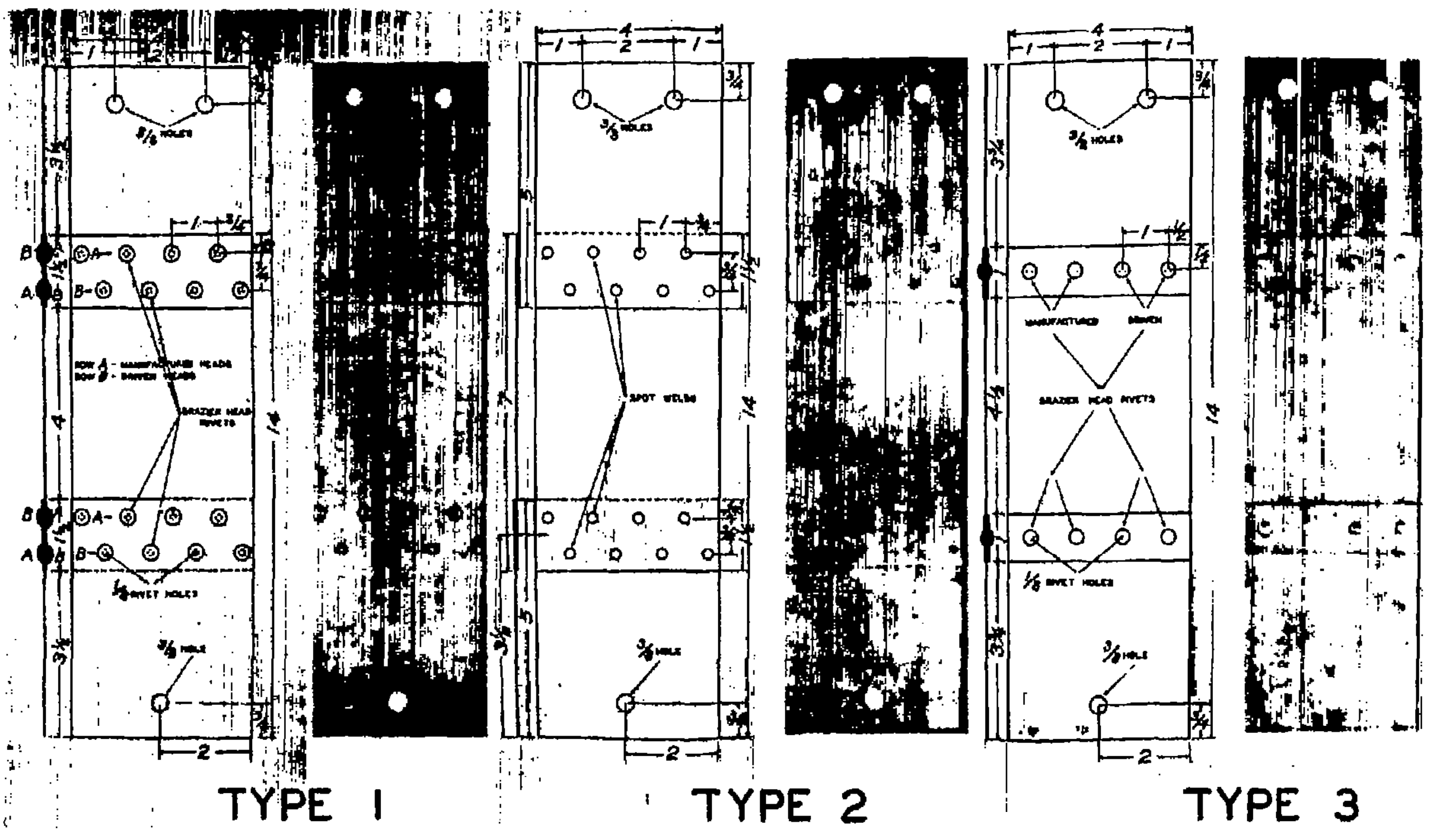

Figure 1.- Types of panel used in the exposure tests. Type 1 panels were designed for investigating the corrosion of rivets or paint coatings; type 2, for welds; and type 3, for dissimilar metals in contact. All dimensions are in inches.

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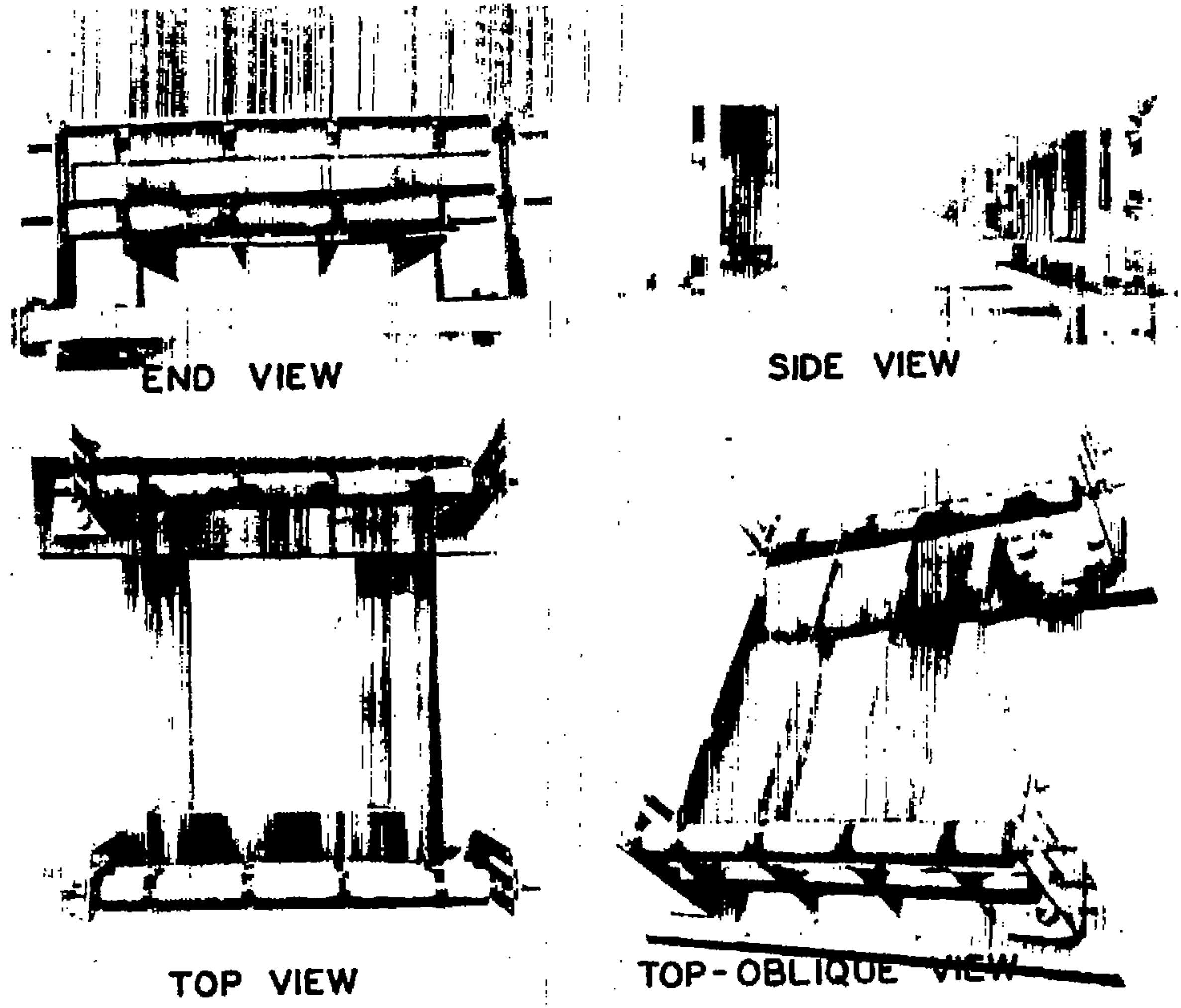

Figure 3.- Views of a model showing details of the method used for suspending panels in the tidewater exposure racks.

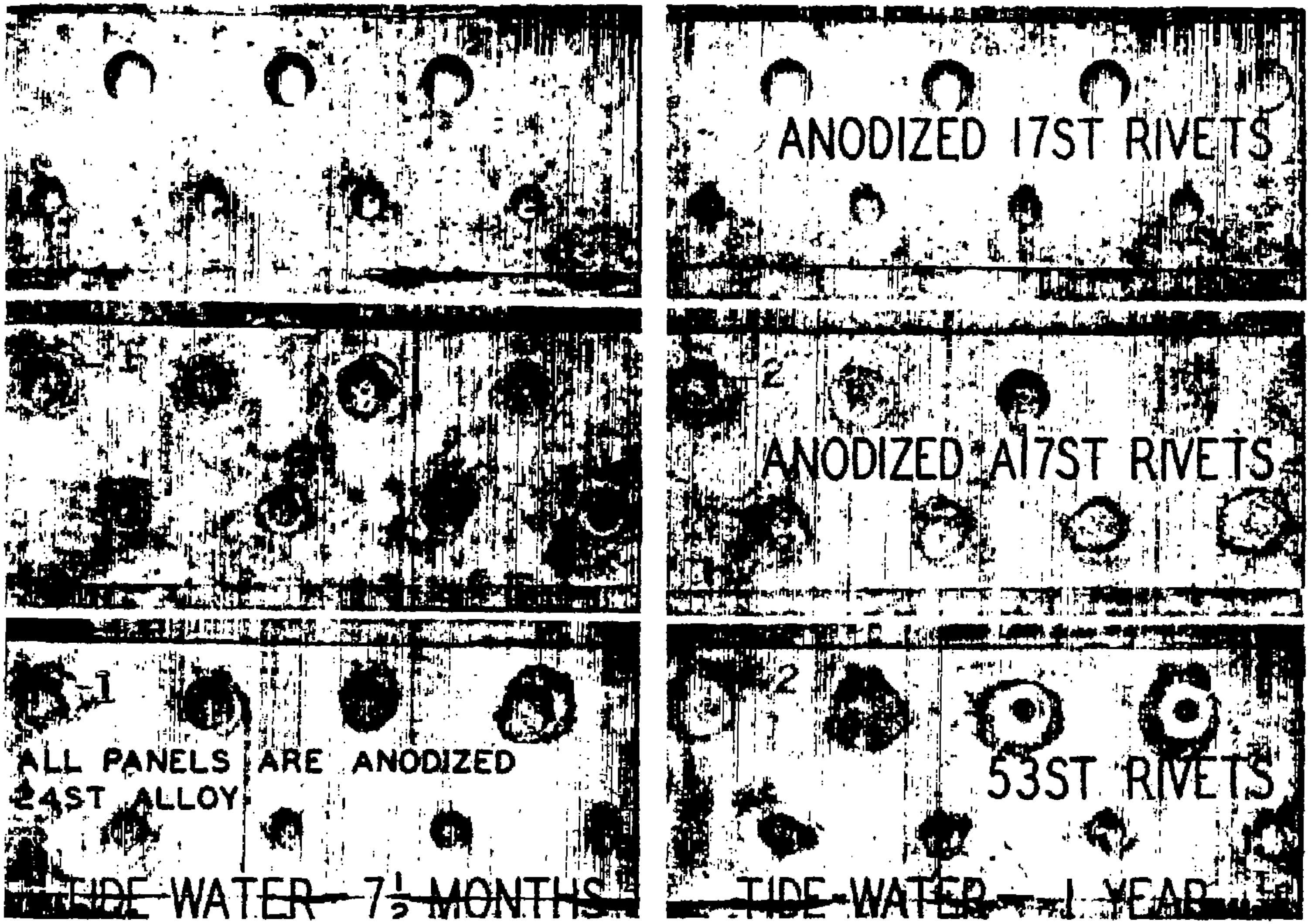

Figure 4.- Rivets used on anodized 24ST alloy panels exposed to tidewater. Note the severe corrosion on anodized A17ST and 53ST rivets, and the relatively slight attack on anodized 17ST rivets. In this, and all of photographs which follow, the large letters at the right apply to the entire horizontal rows, while those at the tops or bottoms apply to the entire vertical rows. × 1

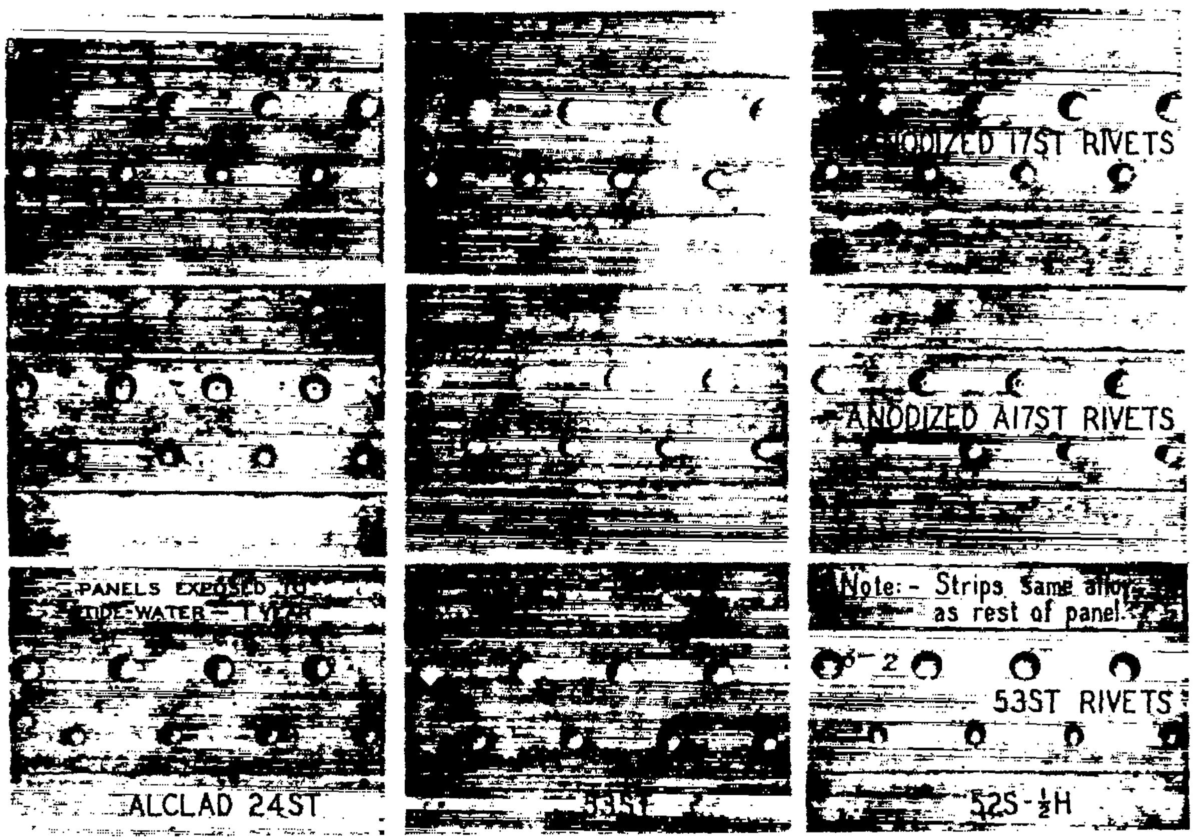

Figure 5.- Rivets used on panels of Alclad 24ST, 53ST, and 52S-1/2H alloys exposed to tidewater. None of the rivets are corroded. × 1/2

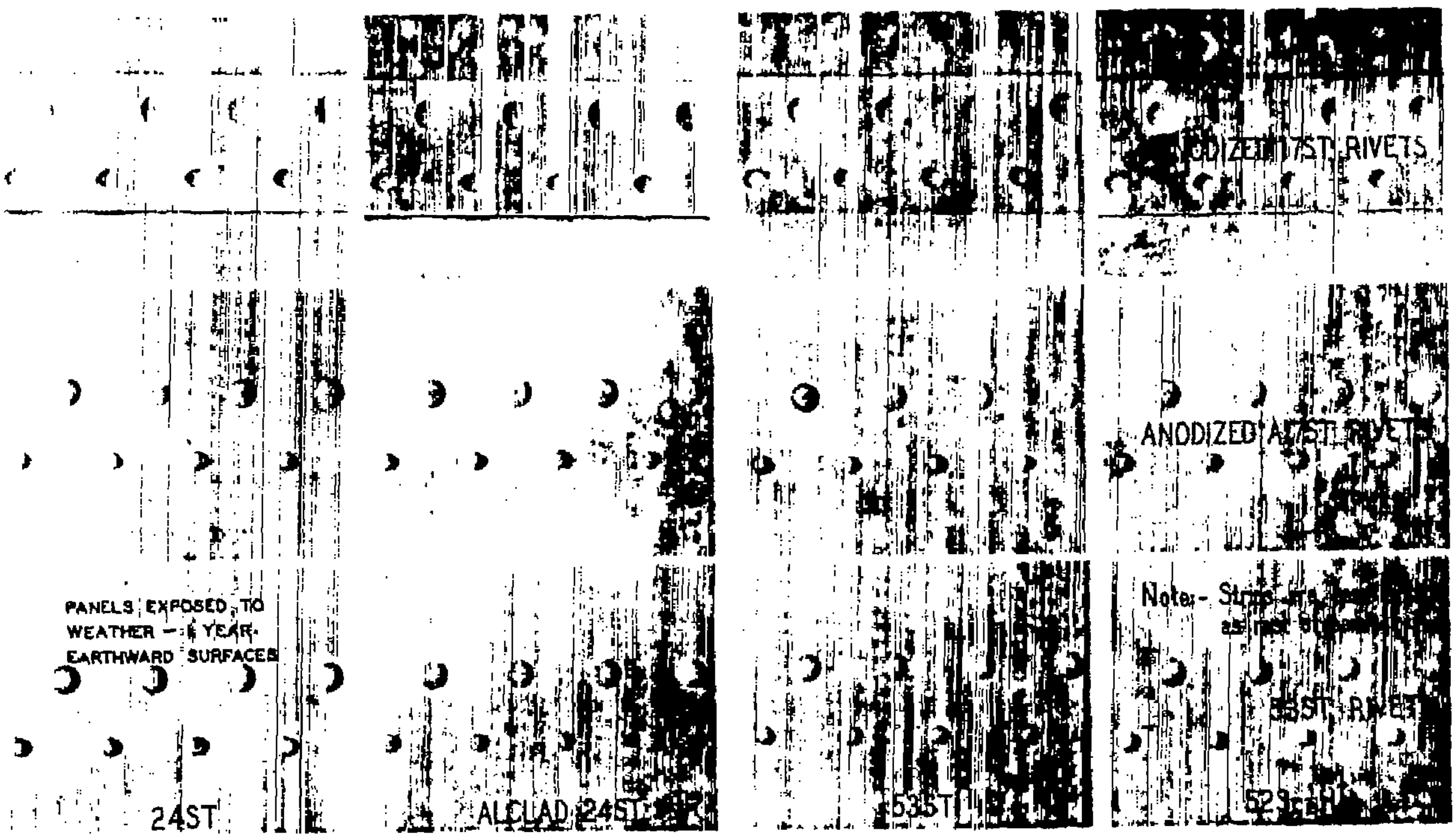

Figure 6.- Rivets used on various aluminum-alloy panels exposed to the weather. The rivets on anodized 24ST alloy that were severely attacked in the tidewater tests (fig. 4) show very little attack here. x 1/2

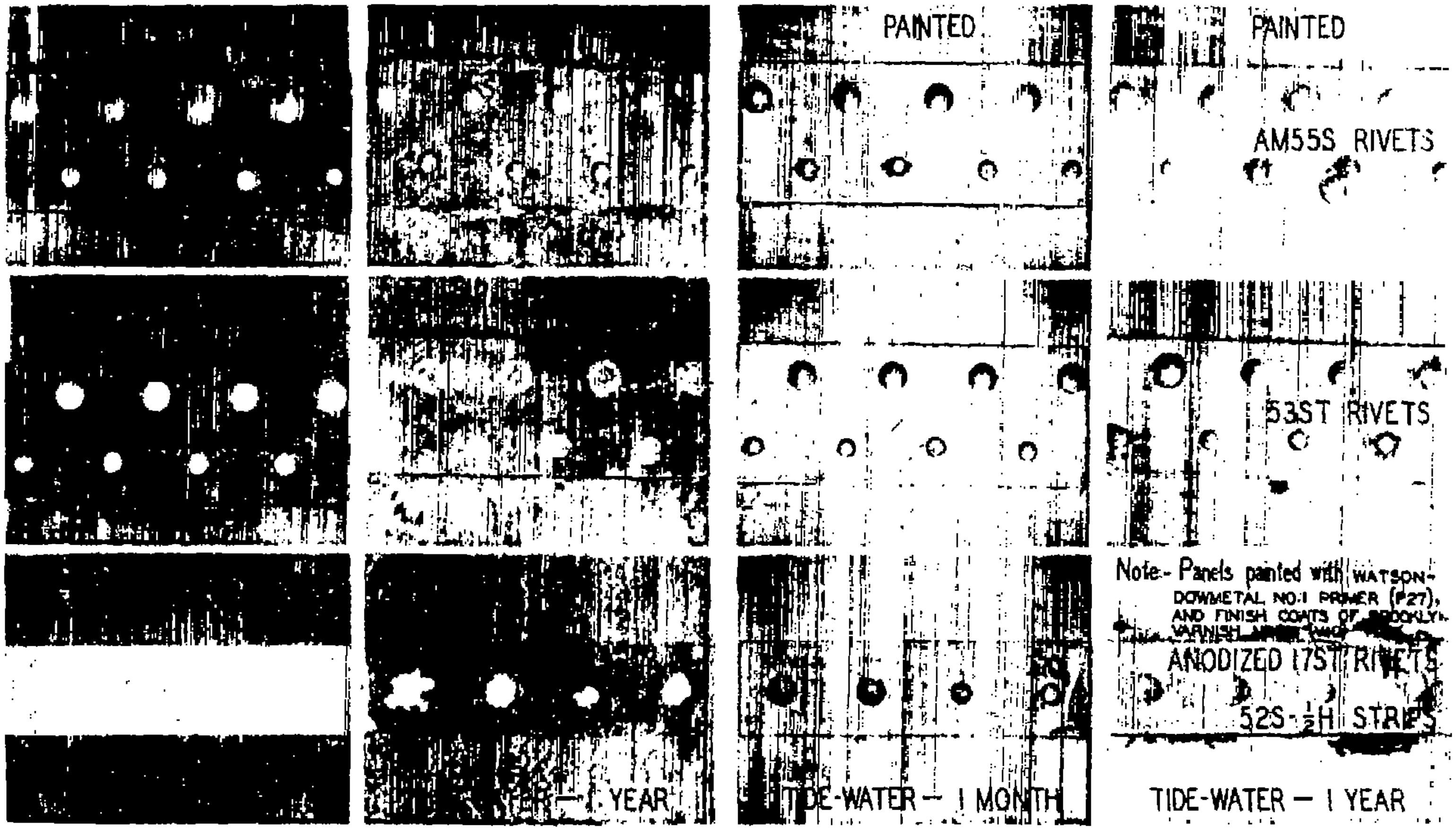

Figure 7.- Rivets on Dowmetal M panels exposed to tidewater. The AM55S rivets proved far superior to the others and the panels on which they were used were likewise the least attacked. The effectiveness of the paint coatings in preventing attack is noteworthy. x ½

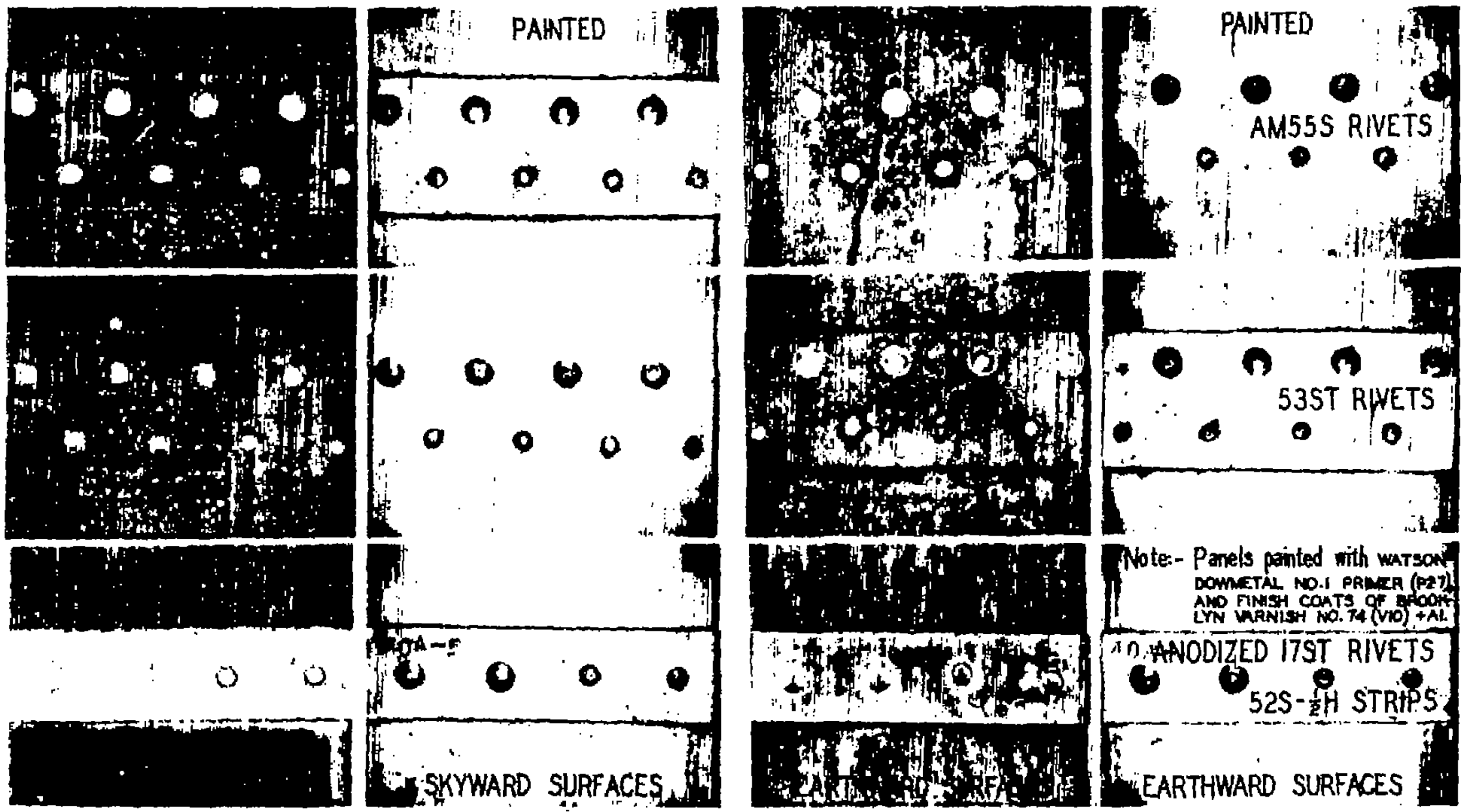

Figure 8.- Rivets on Dowmetal M panels exposed to the weather. The AM55S rivets again show the least attack. Corrosion in general was much less severe than in the tidewater tests (fig. 7). ×½

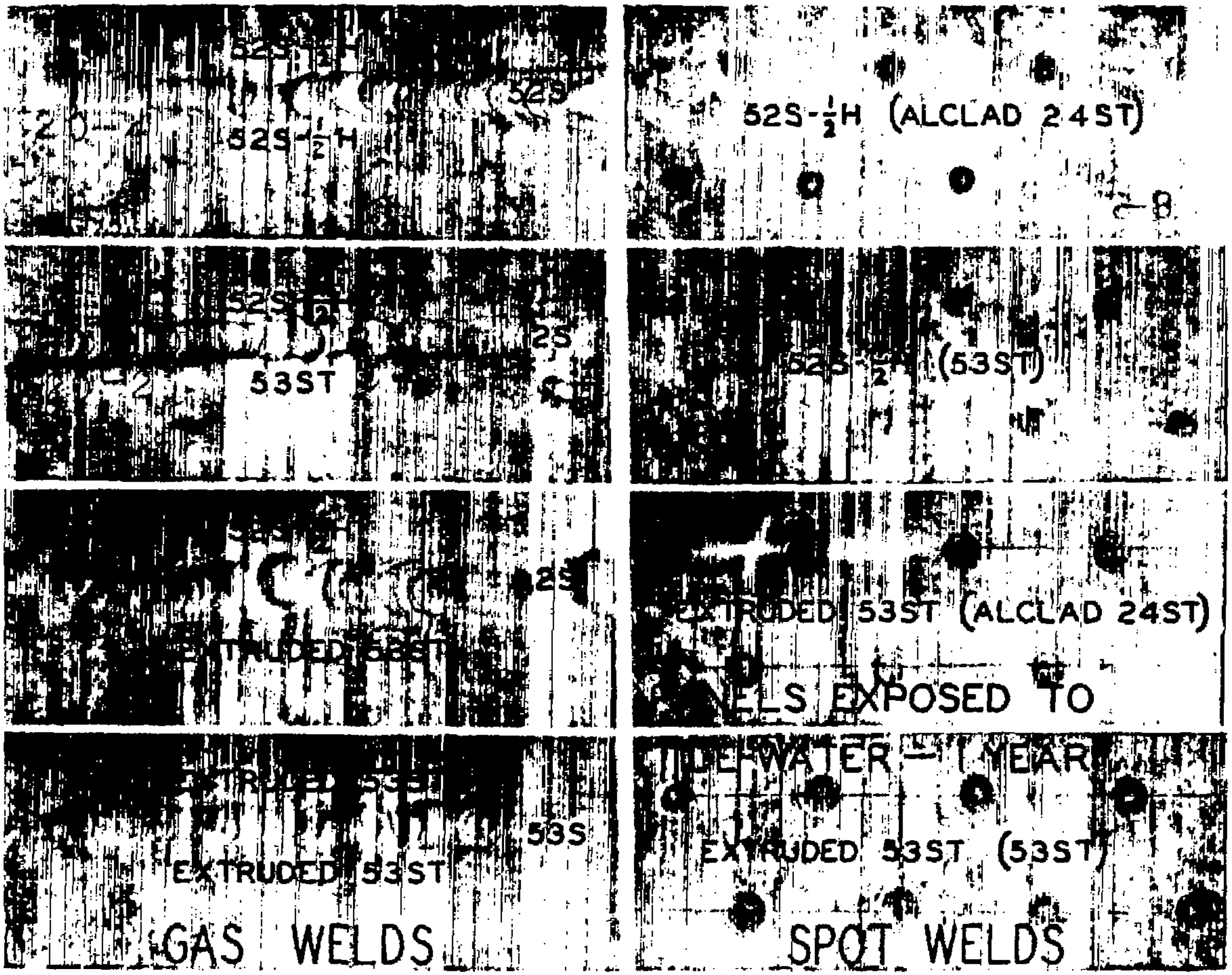

Figure 9.- Welded aluminum-alloy panels exposed to tidewater. Note the absence of corrosion on the gas welds, and the relatively slight amount present on the spot welds. On the spot welds, the alloy within parentheses was joined to the one pictured. The surface shown is the side on which the greater attack occurred on the welds. × 1

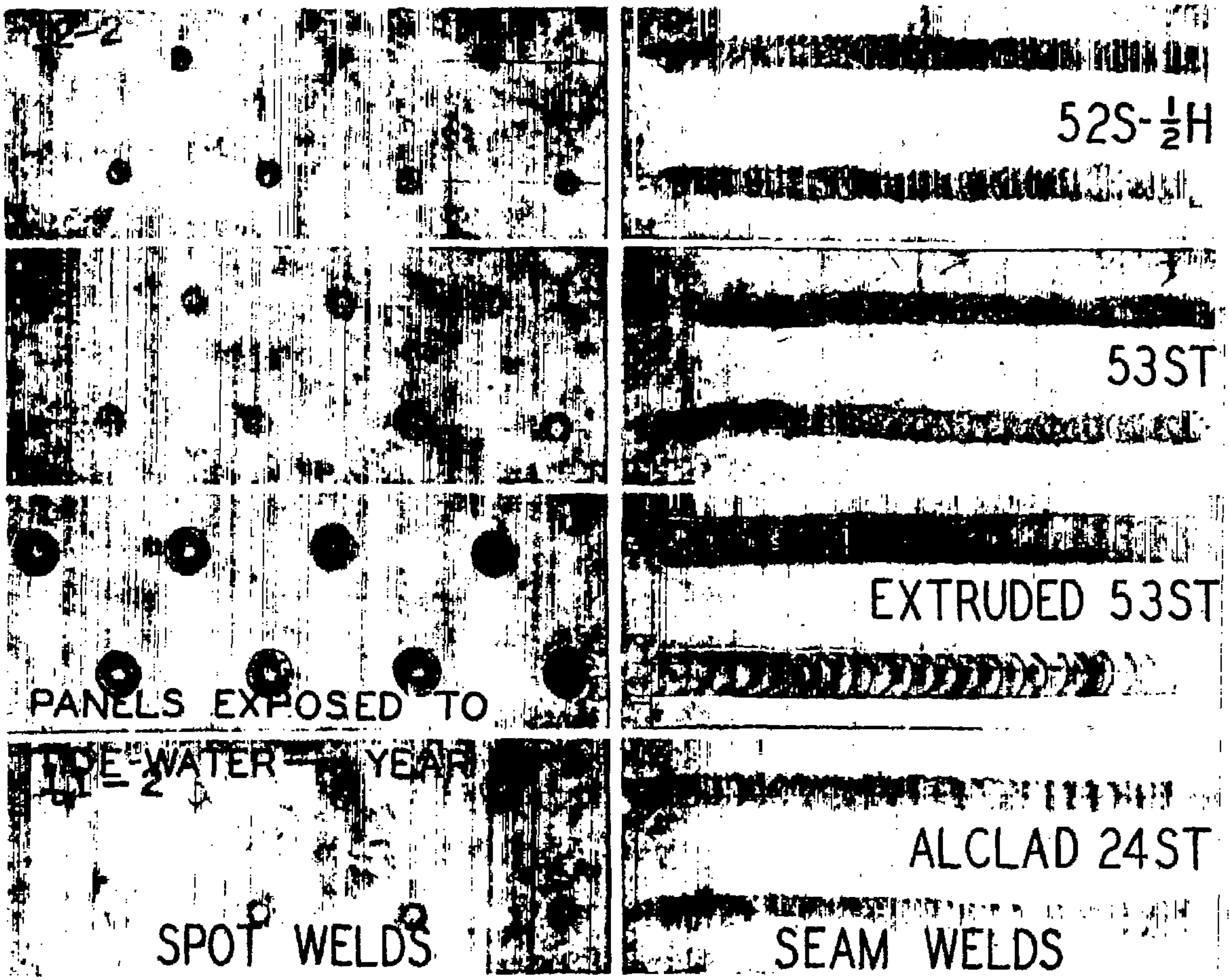

Figure 10.- Welded aluminum-alloy panels exposed to tidewater. The seam welds are somewhat more attacked than the spot welds, the worst corrosion being present on the 53ST sheet alloy. The dark color of some of the welds was caused by the copper electrodes used for welding. × 1

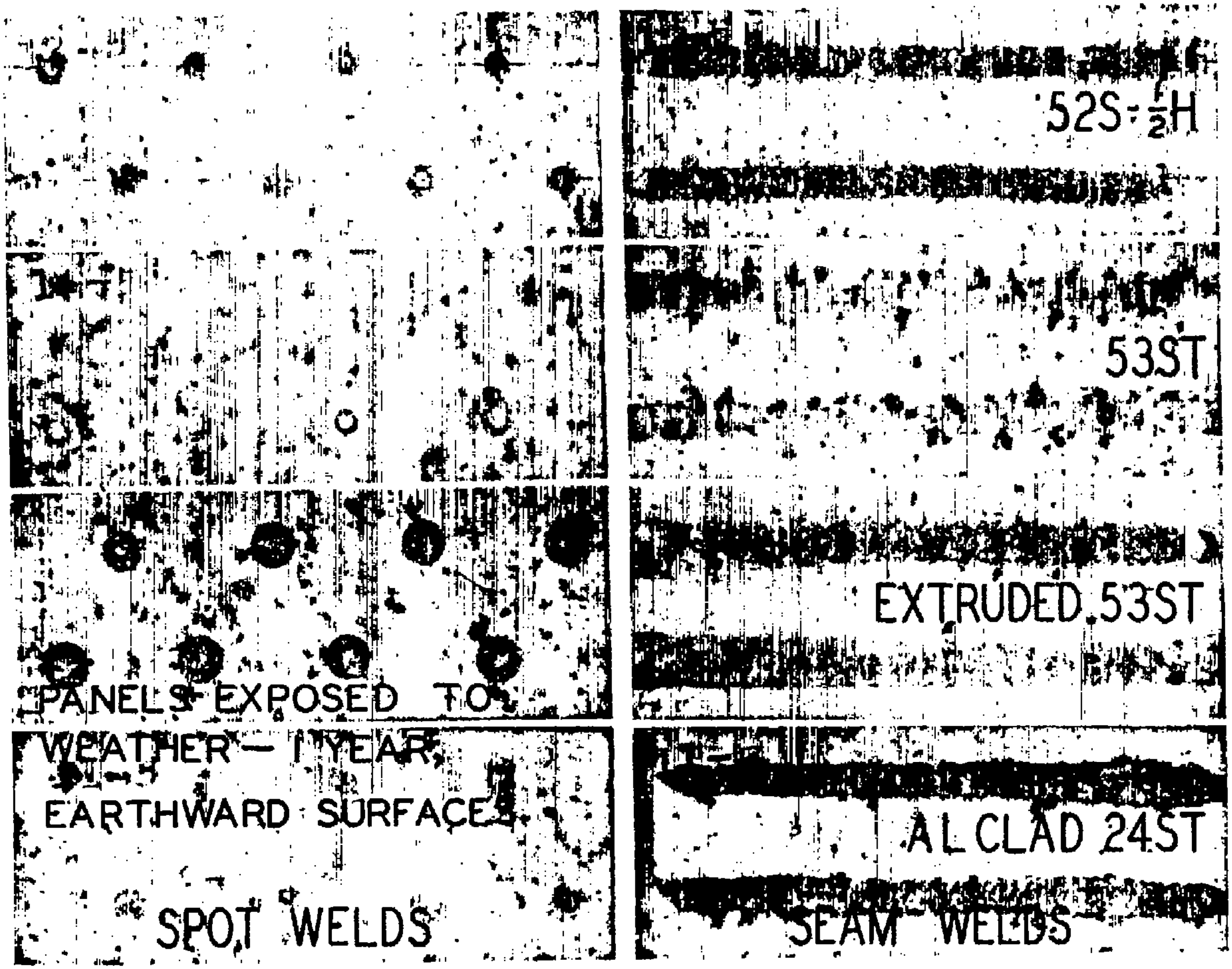

Figure 11.- Welded aluminum-alloy panels exposed to the weather. The attack was more severe, on both types of weld, than in the tidewater tests (fig. 10). ×1

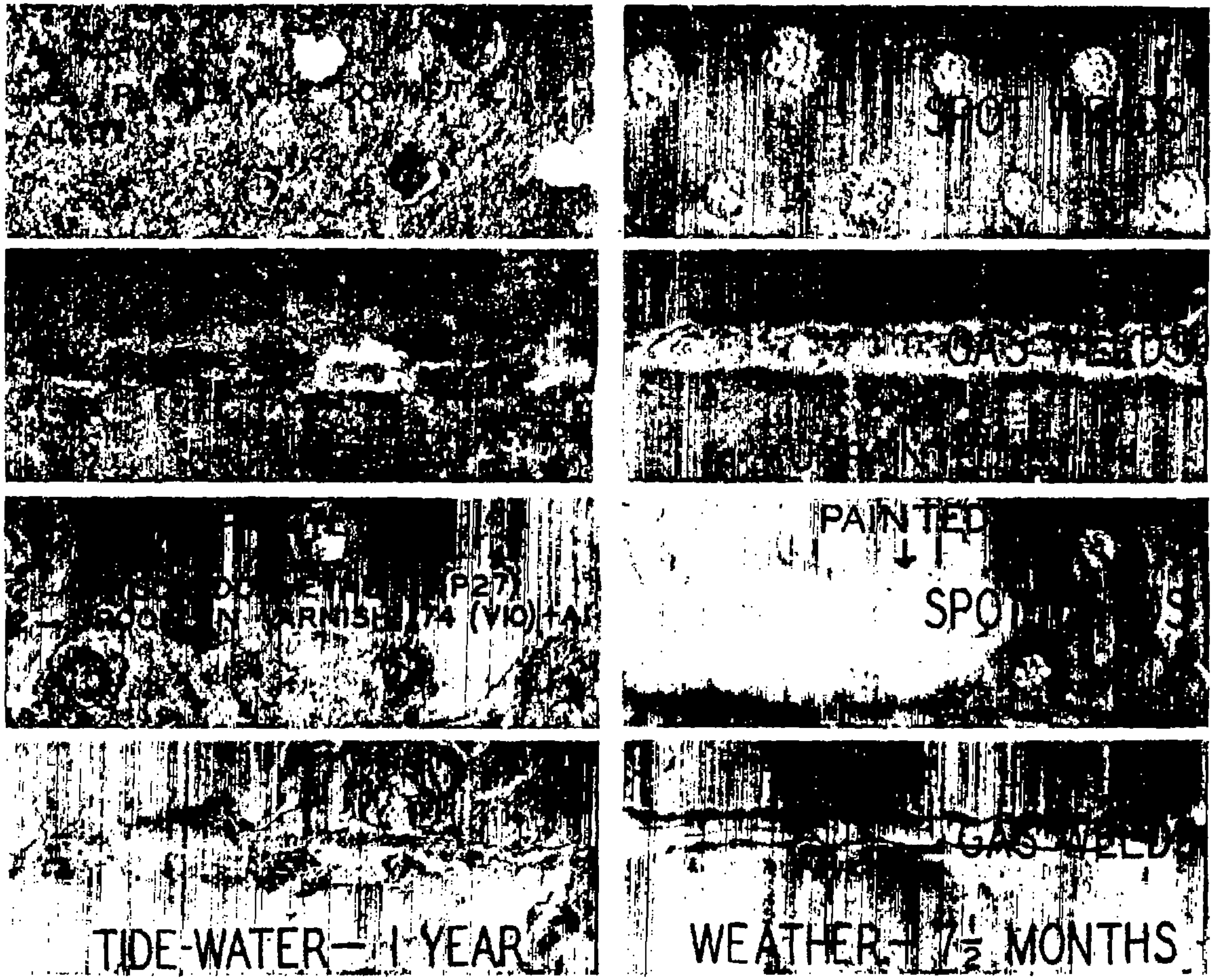

Figure 12.- Welded Dowmetal M alloy panels exposed to tidewater or to the weather. The spot welds were very susceptible to attack, but the gas welds were quite resistant. × 1

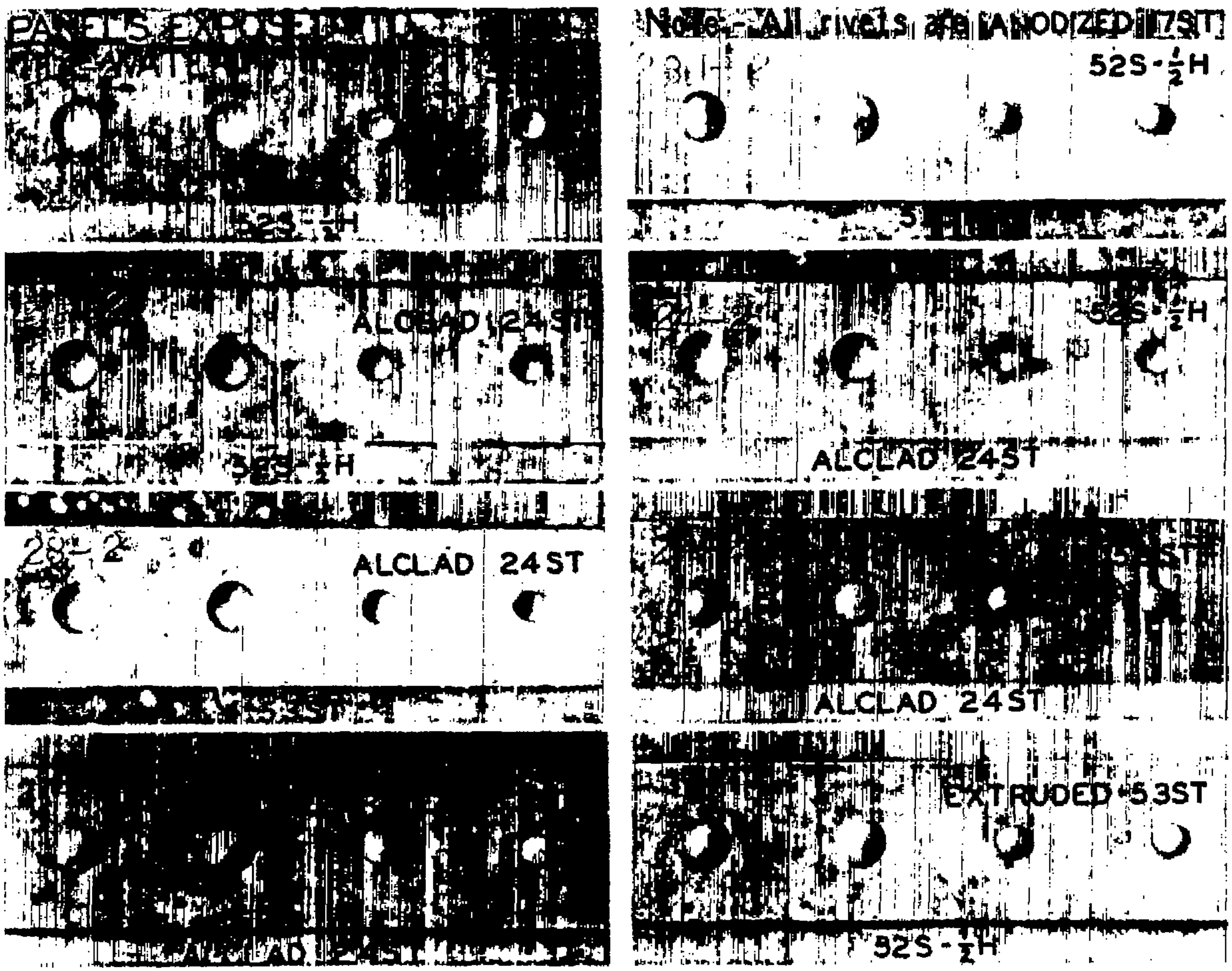

Figure 13.- Panels exposed to tidewater and having various aluminum alloys in contact with each other. Note the absence of corrosion products around the edges of the strips, except for a slight amount on the 52S-1/2H panels with the Alclad 24ST strip. ×1

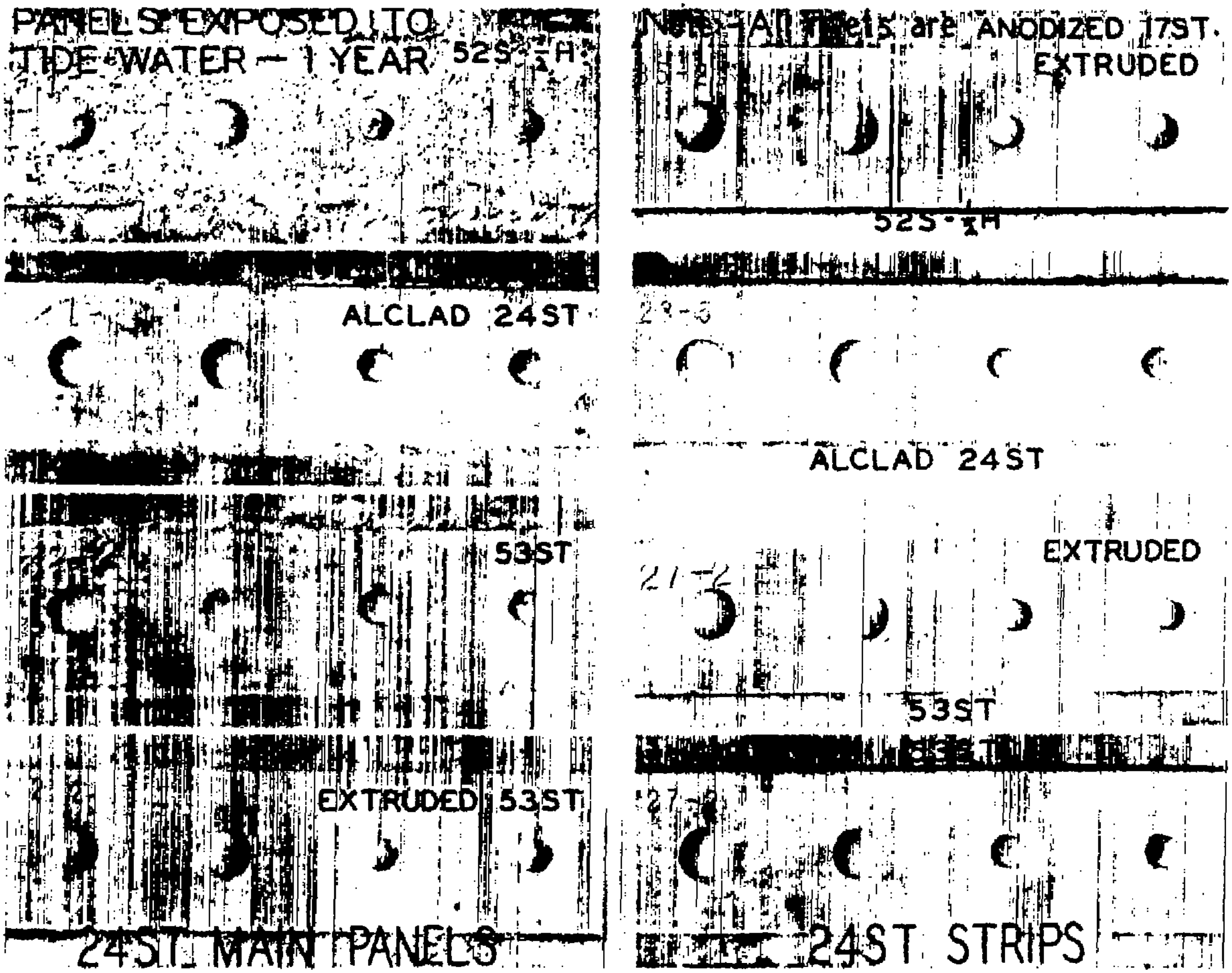

Figure 14.- Panels exposed to tidewater and having 24ST material in contact with other aluminum alloys, which were anodic to it. Note the very severe pitting on the 52S-1/2H strip and the differences in behavior depending on which alloy had the greater area. × 1

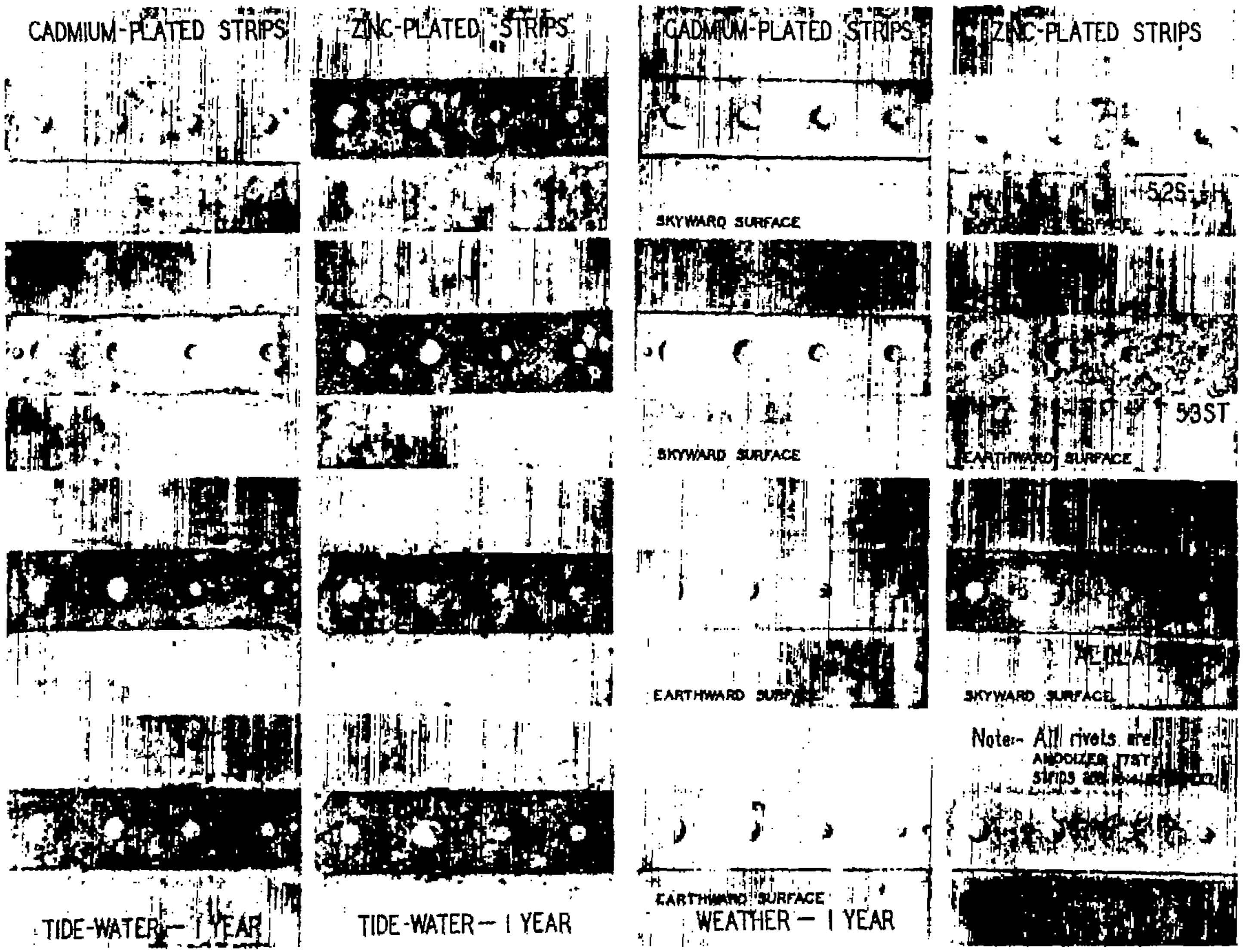

Figure 15.- Panels exposed to tidewater or the weather and having aluminum alloys in contact with cadmium- and zinc-plated X-4130 S.A.E. steel strips. The zinc coating was attacked in all cases, but the cadmium, joined to alloys 52S-1/2H and 53ST, was practically unattacked. x1/2

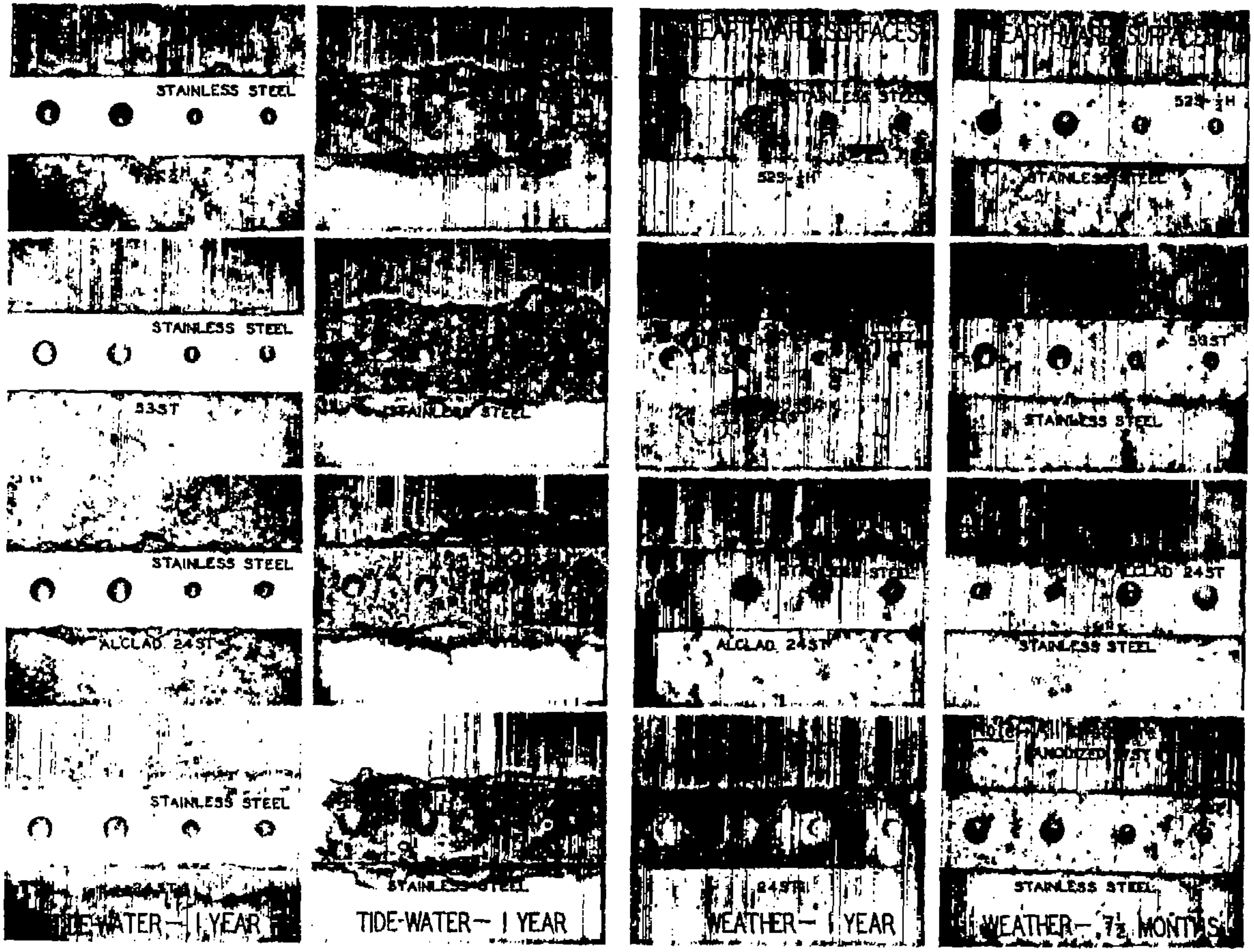

Figure 16.- Panels exposed to tidewater or the weather and having aluminum alloys in contact with stainless steel. The aluminum alloys were severely attacked, with the least corrosion occurring on the 52S-1/2H and 53ST alloys. The attack was much less severe when the area of the aluminum alloy was large as compared with that of the steel. $\times 1/2$

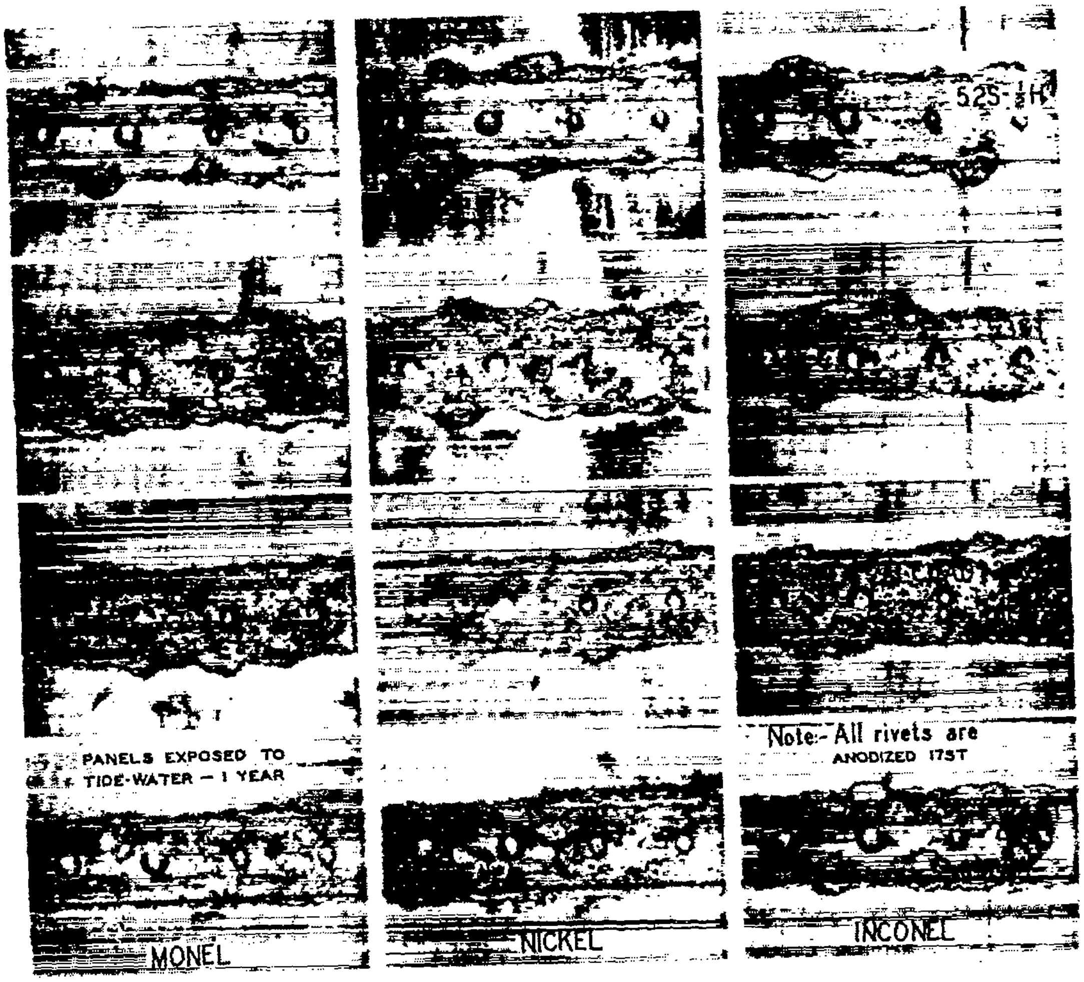

Figure 17.- Panels exposed to tidewater and having aluminum-alloy strips in contact with various nickel alloys. The aluminum alloys were anodic and were severely attacked. × 1/2

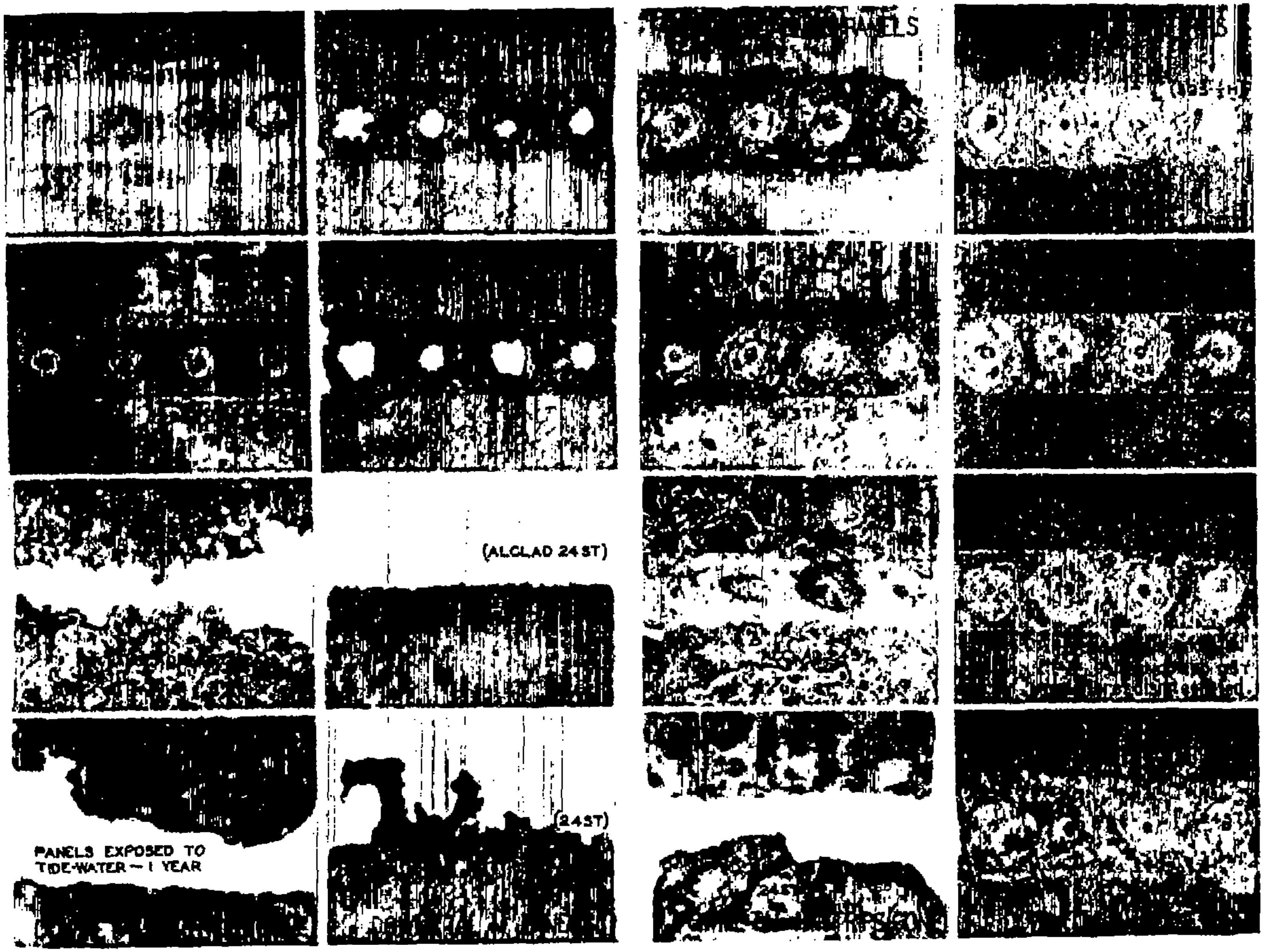

Figure 18.- Unpainted panels exposed to tidewater and having aluminum and magnesium alloys in contact. The potential differences were high and the alloys initially constituting the strips practically all disintegrated. The aluminum alloys were cathodic but were in turn attacked by the corrosion product resulting from attack of the magnesium alloys. $\times 1/2$

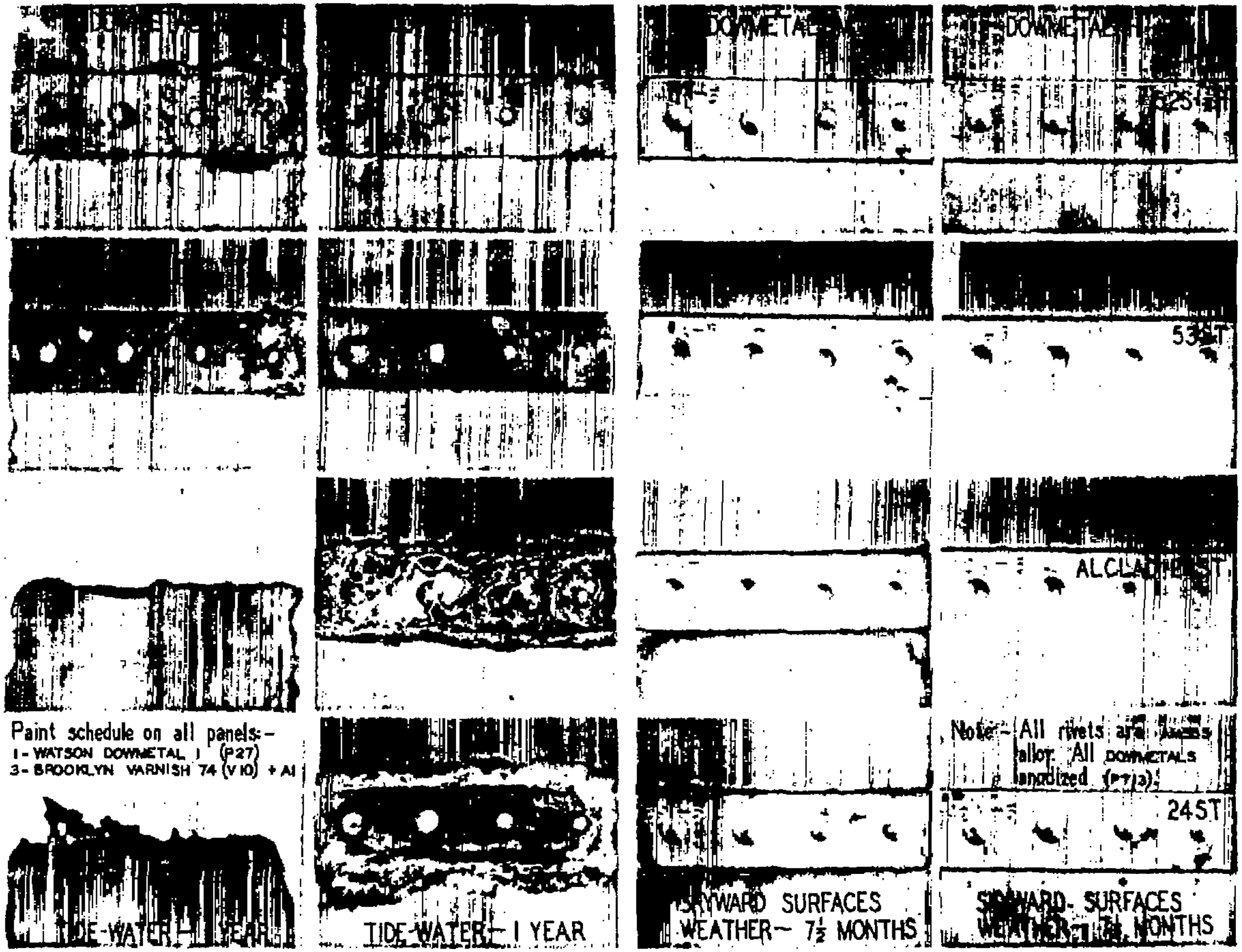

Figure 19.- Painted panels exposed to tidewater or the weather and having aluminum and magnesium alloys joined together. The insulating effect of the paint appreciably retarded corrosion, especially in the weather-exposure tests. Potential differences were highest between the magnesium alloys and the 24ST and Alclad 24ST aluminum alloys. $\times 1/2$

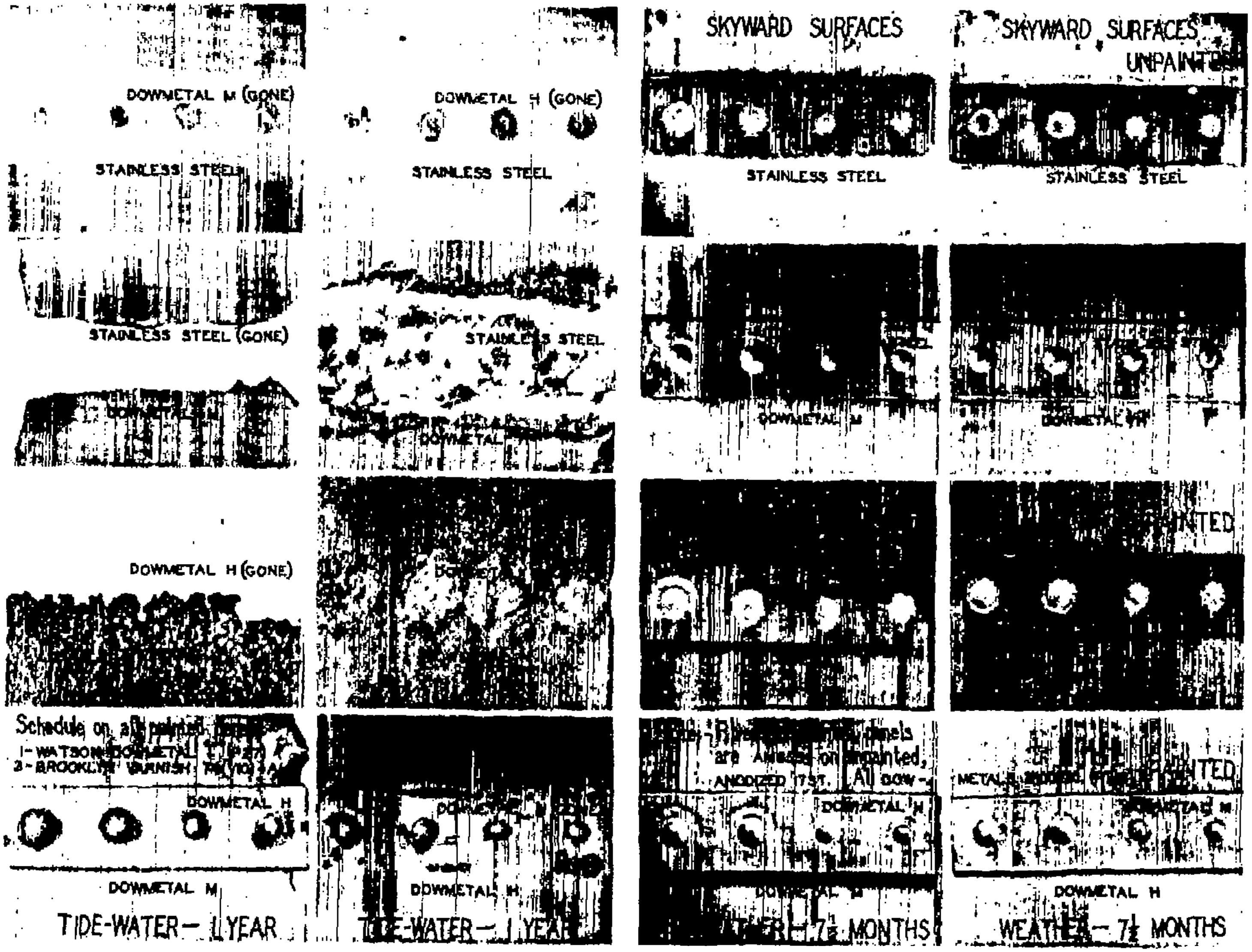

Figure 20.- Panels exposed to tidewater or the weather and having magnesium alloys in contact with each other or with stainless steel. The potential differences involved were higher than for any other contacts investigated, and the magnesium alloys were very rapidly attacked when next to stainless steel. Dowmetal M proved anodic to Dowmetal H. Painting afforded considerable protection, especially in the weather-exposure tests. × 1/2

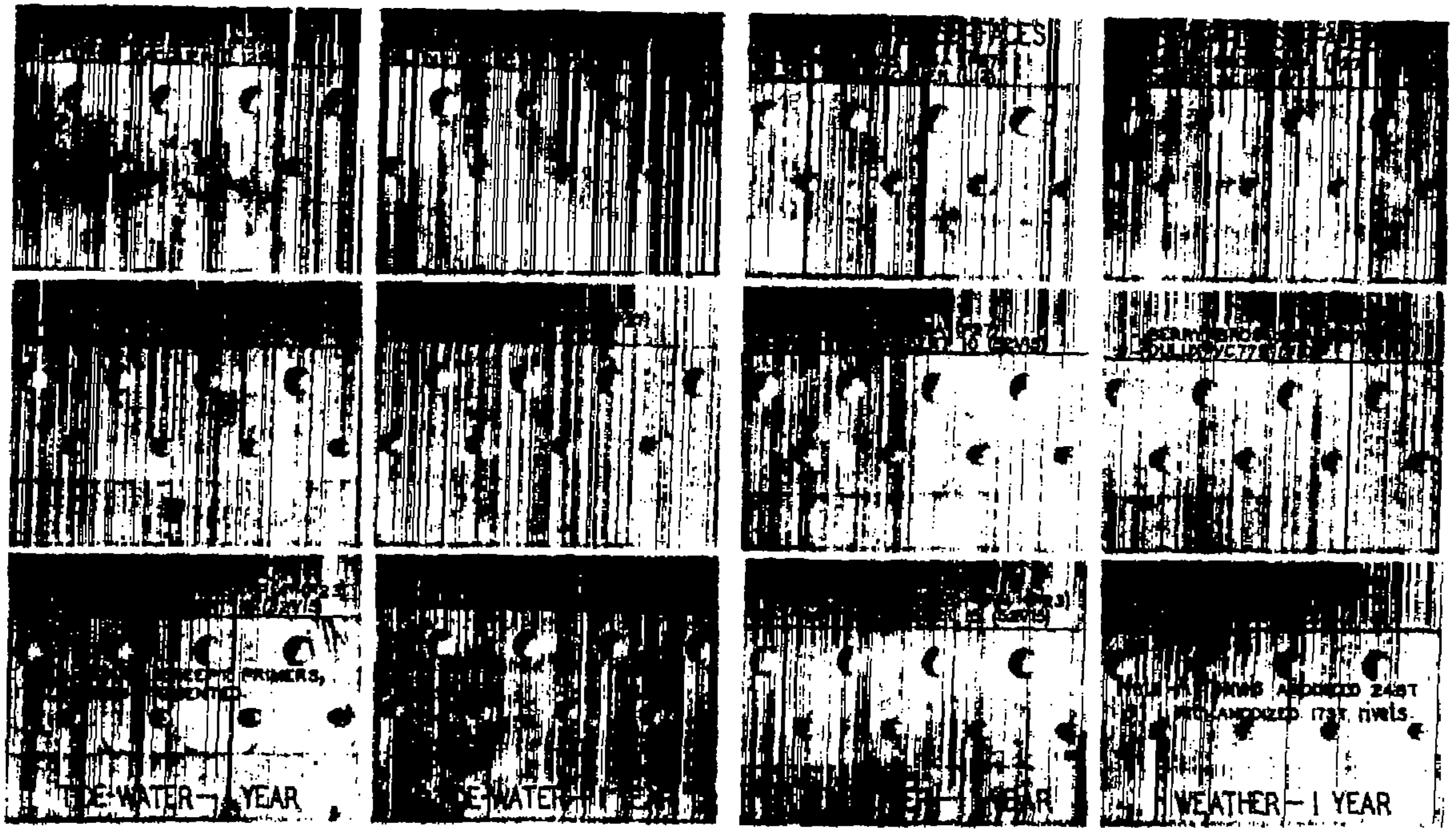

Figure 21.- Anodically treated 24ST panels exposed to tidewater or the weather with various protective paint coatings. Although the coatings all afforded excellent protection under the severe conditions, failure has begun, in the tidewater tests, on the L12a lacquer and on the 52V15 varnish on a P23 primer. $\times 1/2$

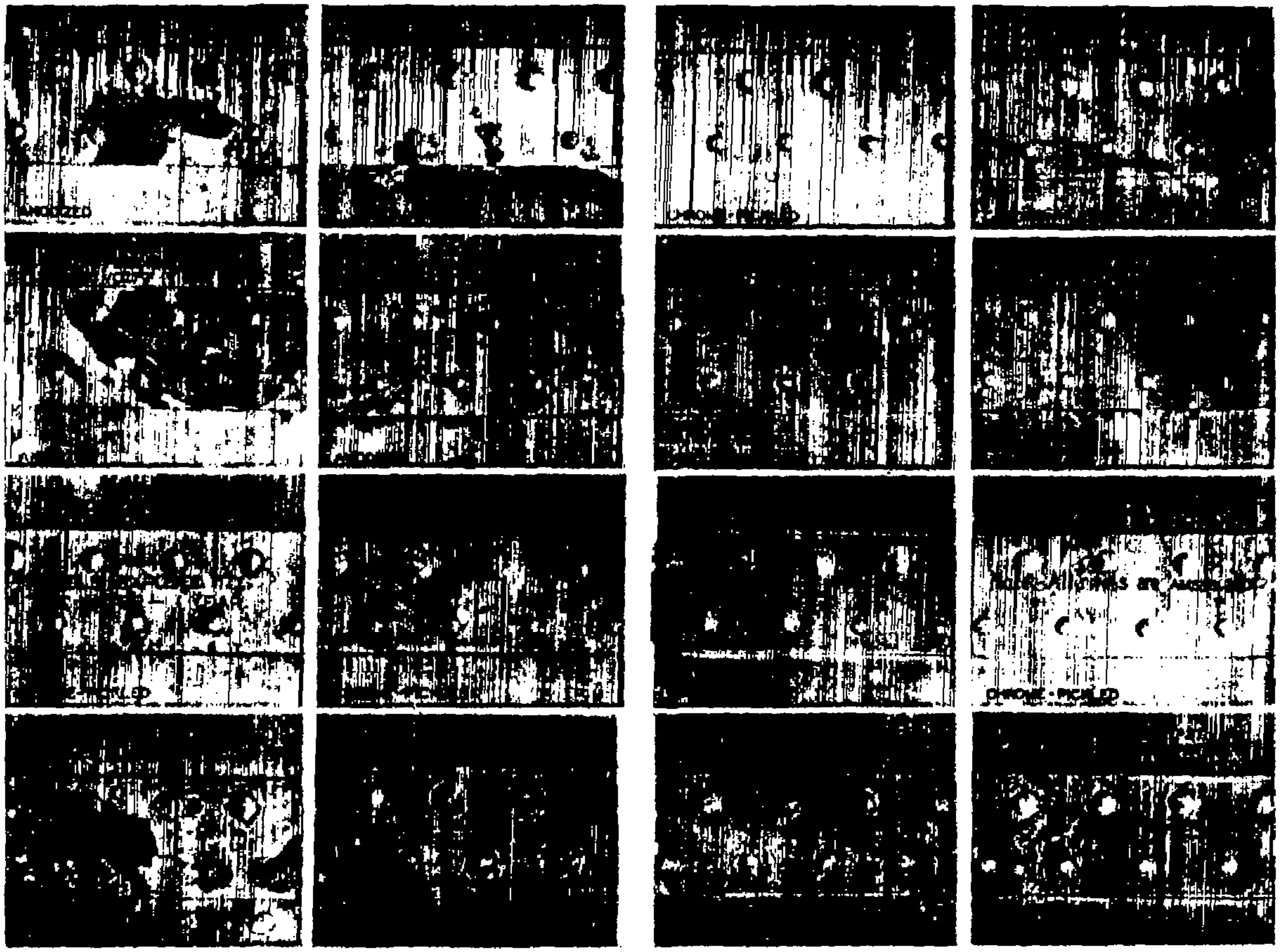

Figure 22.- Magnesium-alloy panels exposed to tidewater with various protective paint coatings. The schedules having the Bakelite XE3944 or the Brooklyn 74 varnishes over a P-27 primer afforded excellent protection. Note the difference in behavior of various coatings conforming to Navy Specification V10. The chrome-pickle surface treatment proved somewhat more effective than the anodic treatment on the Dowmetal H panels. $\times 1/2$

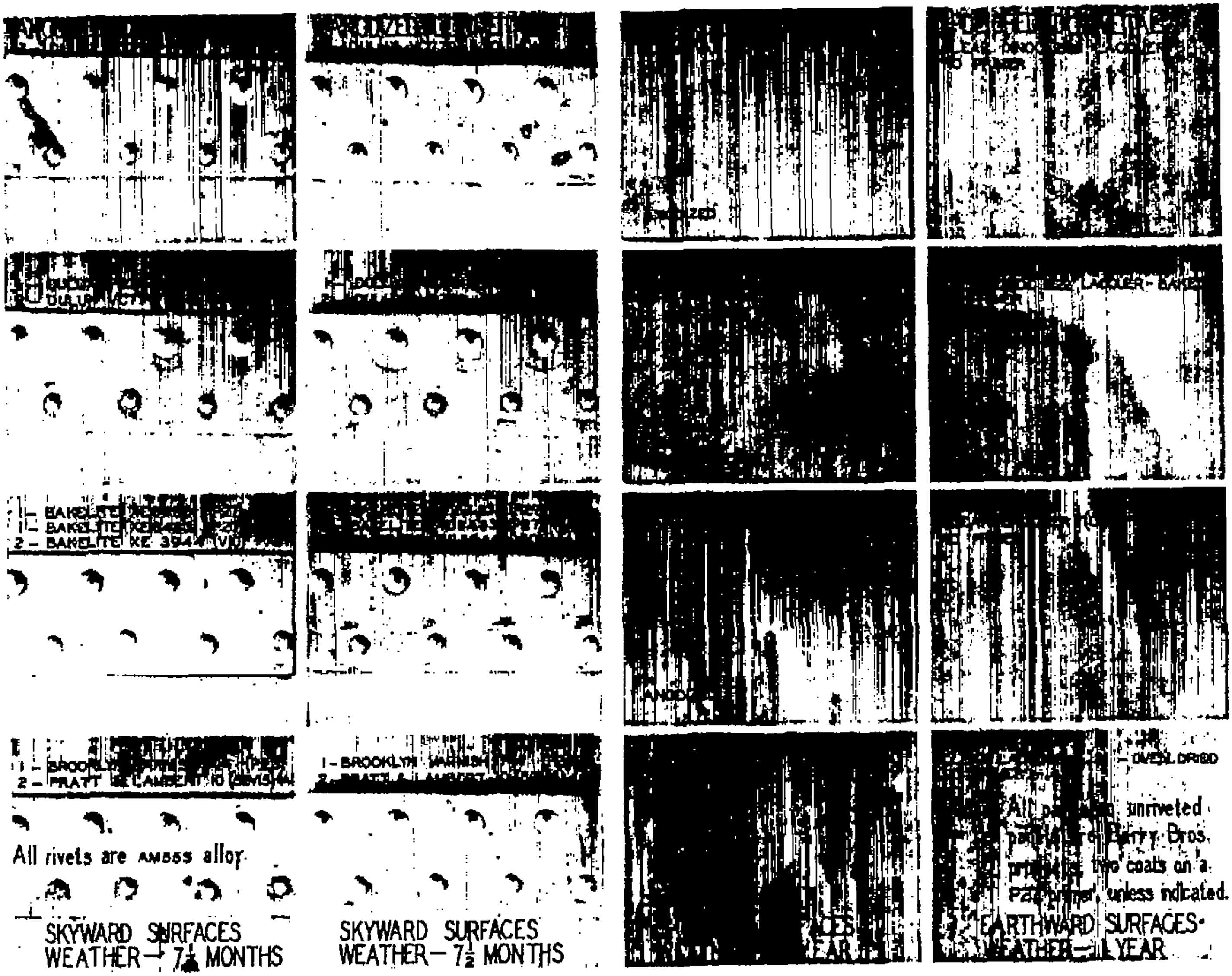

Figure 23.- Magnesium-alloy panels exposed to the weather with various protective paint coatings. Note the inferiority of the unpigmented paints, especially those applied to polished surfaces, as evidenced by numerous pin-point areas of corrosion product formed beneath the coatings. × 1/2

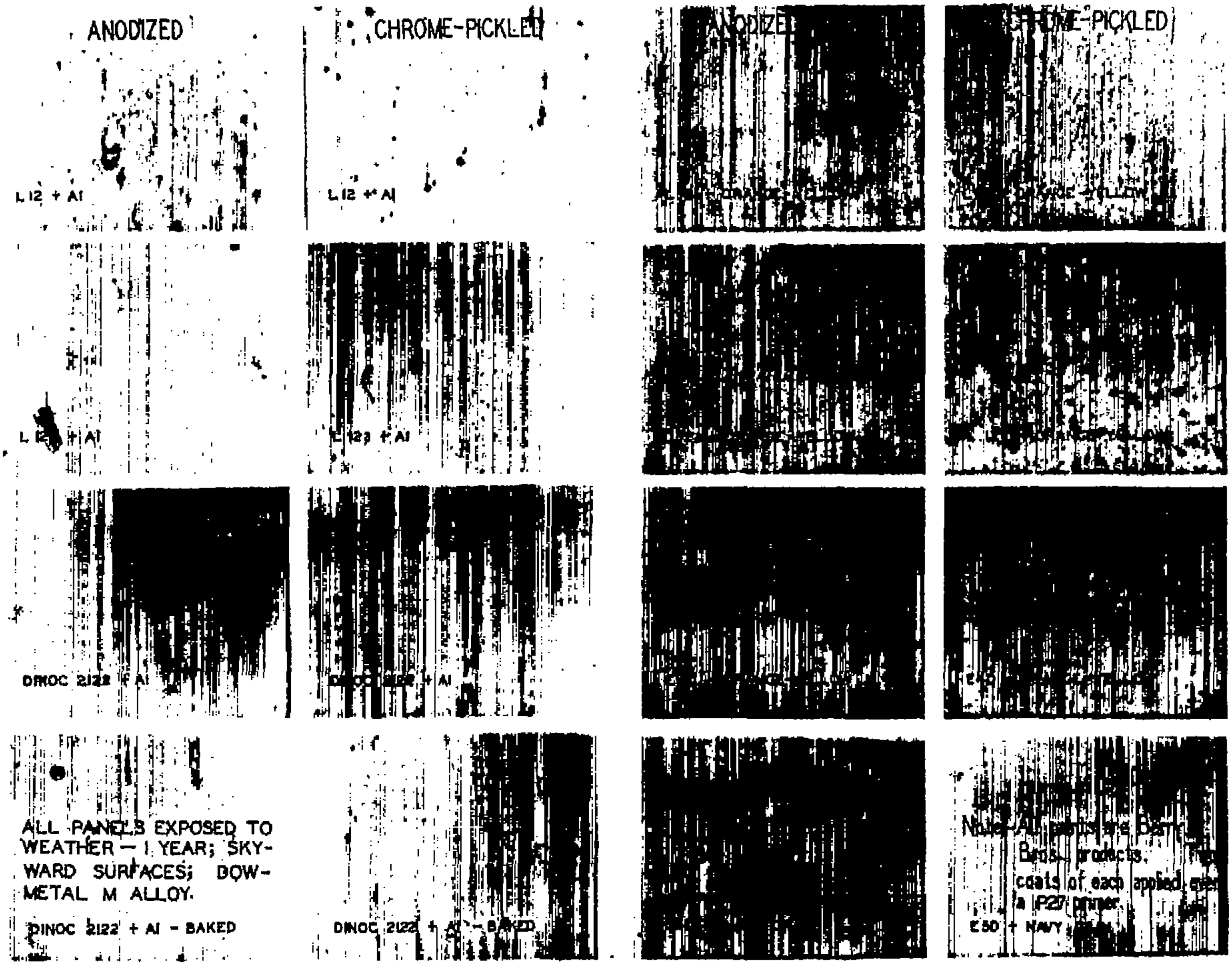

Figure 24.- Magnesium-alloy panels exposed to the weather with various protective paint coatings applied over chrome-pickled or anodized surfaces. Failures occurred on all these panels. The Navy gray coatings chalked badly. The anodic treatment proved somewhat superior to the chrome-pickle treatment, but not enough so to be of much practical significance. × 1/2

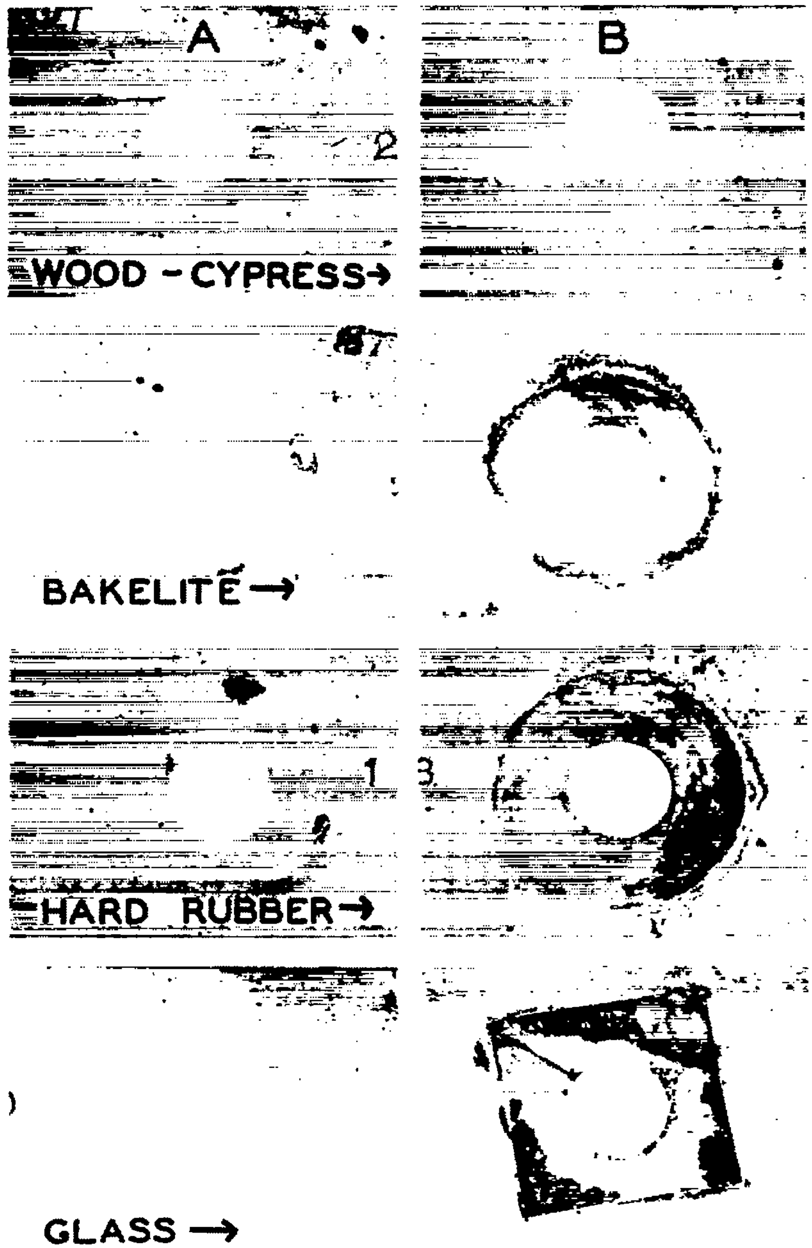

Figure 25.- Relative efficiencies of various materials used as separators (fig. 3) for suspending stainless-steel panels in the tidewater tests. Column A panels were suspended by the four-point method; Column B panels were in contact with the supporting medium over an area approximating 1 square inch. All panels shown were exposed for 1 year. Note the superiority of the point method of suspension. x 1

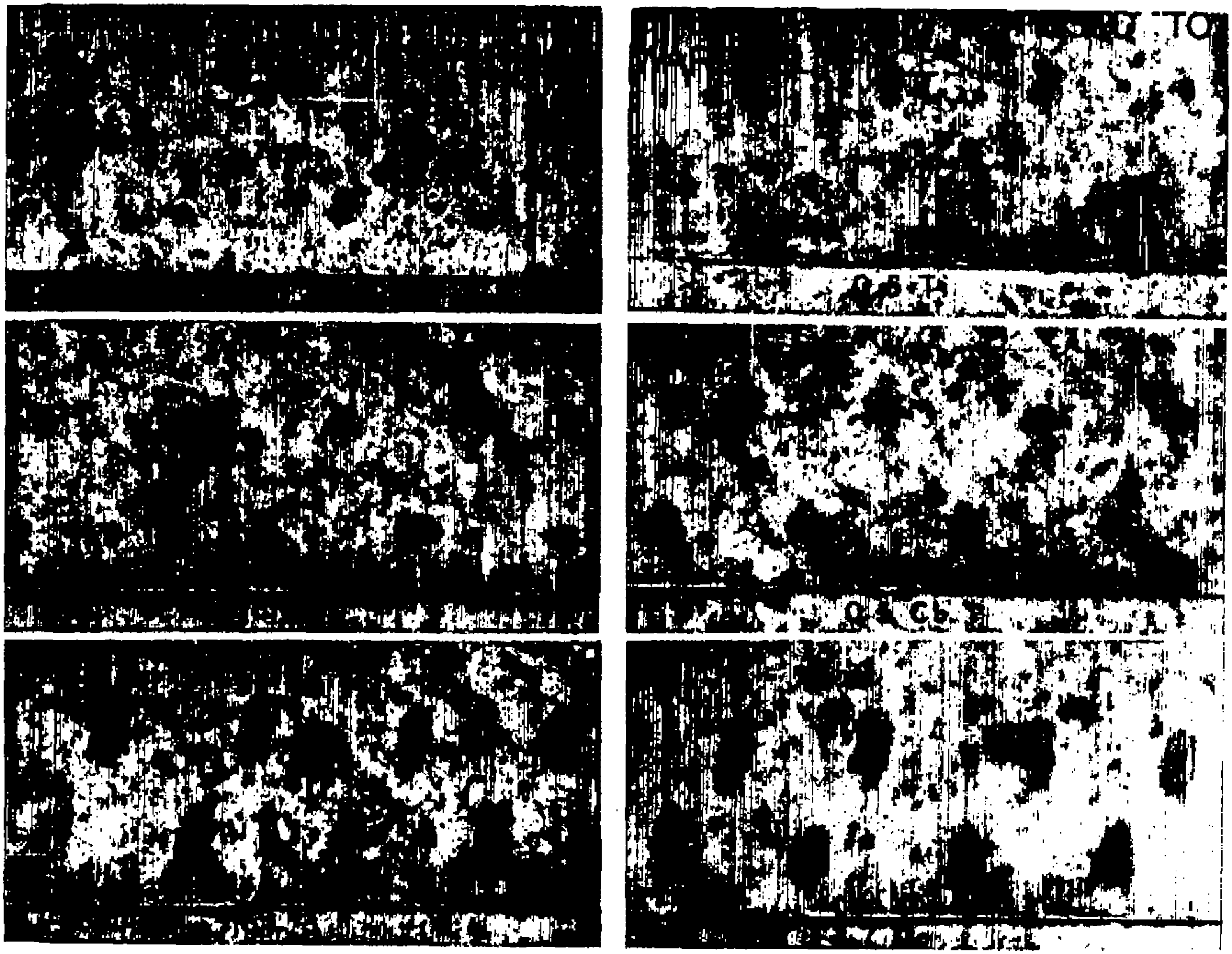

Figure 26.- Stainless-steel panels of various compositions, exposed to the weather. Note the prevalence of rust that formed in thin, but adherent layers and tended to be worse on the welds than on the rest of the panels. The steel containing molybdenum proved appreciably more corrosion resistant than the others. ×1

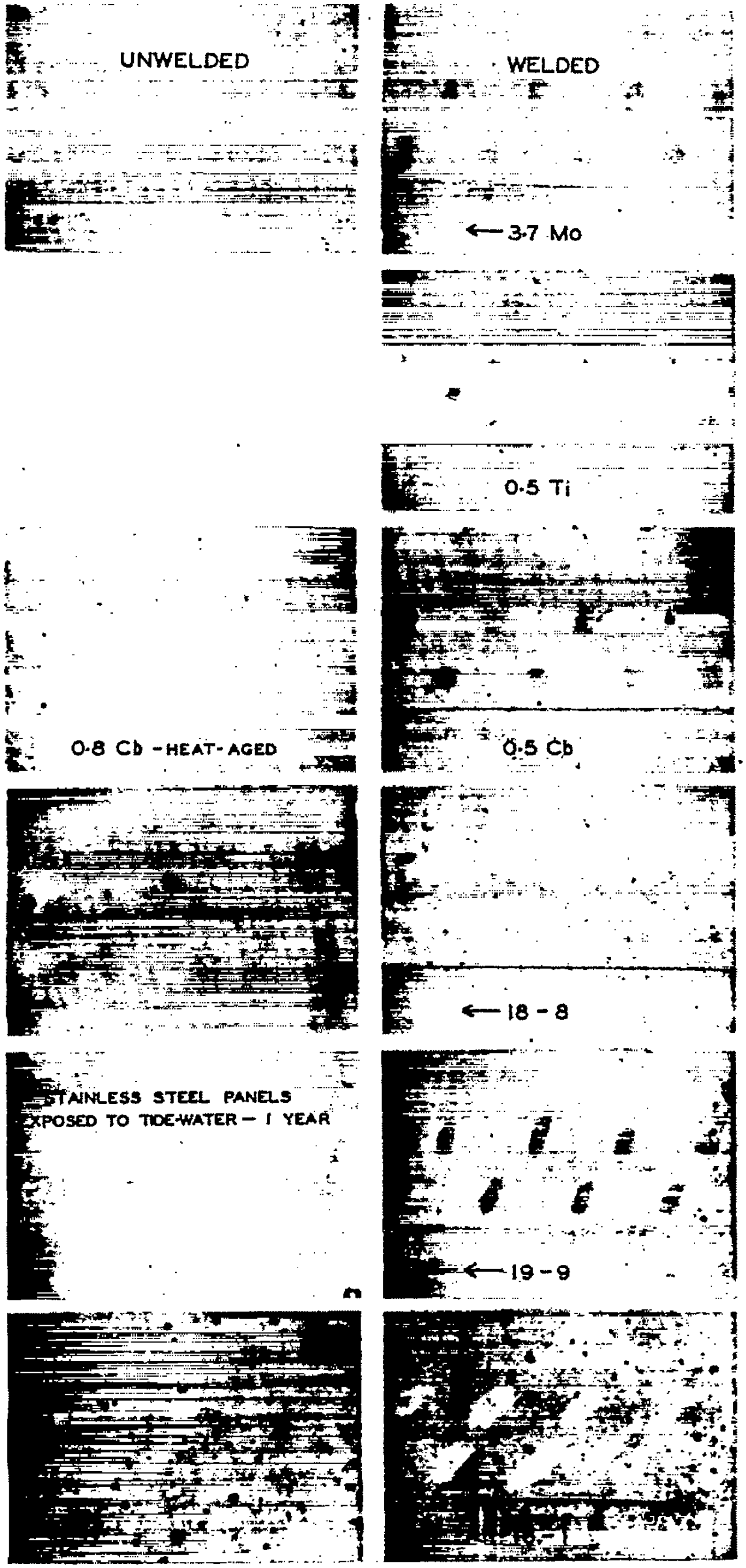

Figure 27.- Stainless-steel panels exposed to tidewater for one year. The attack was much less severe than in the weather-exposure tests (fig. 26), but the 16-1 chromium-nickel alloy again proved the most susceptible to attack. × 1/2